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ABSTRACT

This study examines how the cost of engineering education changes with the size and characteristics of programs, and tries to establish whether there is some minimum scale at which point engineering education becomes financially viable, and considers the manner in which financial viability is affected by program characteristics. Chapter I presents the approach to the study. Chapter II discusses the faculty requirements related to the curricula, including the ground rules and characteristics of a baseline curriculum and constraints as factors in faculty workload. Chapter III deals with the academic workload for an electrical engineering college. Chapter IV discusses the utilization of faculty slack time. Chapter V discusses the effect of program enhancement on faculty requirements, such as increasing both the number of subjects offered and class size. Chapter VI deals with faculty requirements in a college with three major areas, and Chapter VII with the effect of graduate education and research on faculty requirements. Possible extensions of the models are presented in Chapter VIII. Recommendations on how to calculate faculty requirements are presented in the appendix. (AF)

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Guy Black

ON THE COST OF ENGINEERING EDUCATION

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ON THE COST OF ENGINEERING EDUCATION

Guy Black

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Dr. Black studied at Harvard University and received a doctorate in economics from the University of Chicago in 1951.

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INTRODUCTION

This paper was prepared during the summer of 1970 as part of a larger study of financial management of private universities undertaken at The George Washington University and funded by the Ford Foundation. It deals principally with the number of faculty required as a function of enrollment and program characteristics. Faculty are, of course, the crucial element in determining the cost of education. In a complete cost study, faculty salaries, facility and other costs of engineering education must be included--a fairly mechanical procedure that can be undertaken by anyone with some skill in educational planning or industrial engineering.

That this study deals with engineering education is partly a matter of convenience. The thrust of the effort is application to higher education of a basic methodology for estimating functional relationships. The methodology is especially useful where the more common statistical methods will not yield truly structural equations and data are unavailable. This is a larger claim than meets the eye; the author doubts that there is any example of parameters of a structural cost function being accurately estimated from data collected from a sample of educational institutions. The enormous variation in institutional characteristics compared with the available data makes structural relevance a near impossibility. Engineering education was a good vehicle for testing a methodology of cost functions which can be applied to other education. The conceptual basis is by no means new, but it is now established that it is applicable to education. Study structure, procedures and information needs have been identified so that additional costing studies can proceed more expeditiously.

As will be seen, the thrust of this paper generally is to answer the question, what are the minimum faculty requirements consistent with a specified academic activity. A principal purpose of this approach is to make possible a comparison of a minimum faculty with the faculty that is actually employed, in order to judge the effectiveness of faculty utilization and the extent of cost reductions possible without jeopardizing academic performance. In the process, a number of useful, sometimes unexpected, insights have resulted.

The planning, programming and budgeting approach to financial management depends critically on analytical methods such as cost-benefit and cost-effectiveness analysis. An essential ingredient in such methods is some means of determining how cost varied with variations in program characteristics. An earlier paper entitled "The Basic Financial Model of the University" has been seen by some readers. An integral element of the model was functions relating cost to enrollment. That paper was entirely conceptual; this paper quantifies cost functions of types that would be used with such models in combination with parallel information on benefits or yields from education. Having both would remove the basic financial model from pure theory to the status of a practical tool in financial analysis of higher education.

This paper is being given limited distribution with a request that comments be forwarded to the author. I am anxious to receive reactions, corrections, and comments of all sorts.

I would like to acknowledge the encouragement of Mr. W. D. Johnson, Director of the Budget of The George Washington University, and the assistance of Mr. Robert D. Shoup and Mr. Richard Rosenbluth. Finally I would like to express my appreciation for the indispensable assistance of Mrs. Carolyn Larson in the preparation of this paper.

Guy Black

The George Washington University
September 30, 1970

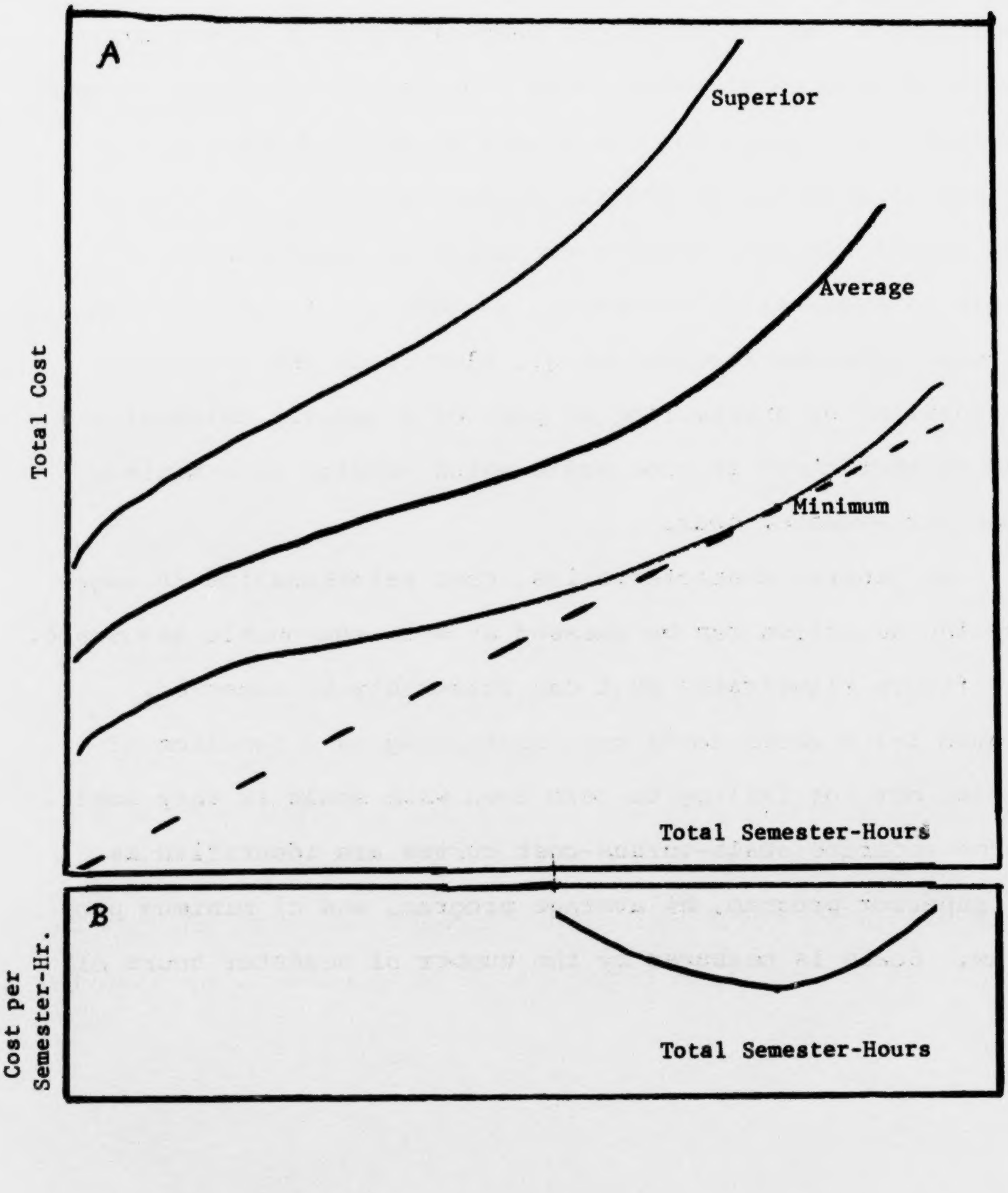
I. AN APPROACH TO THE COST OF ENGINEERING EDUCATION

The cost of engineering education as a function of the scale of the educational establishment and program characteristics is the subject of this study. The purpose is to examine how cost changes with the size and characteristics of programs, and to establish whether there is some minimum scale of program at which point engineering education becomes financially viable, and the manner in which financial viability is affected by program characteristics. As part of the effort, it will examine economies or diseconomies of scale in engineering education, whether joint costs of running several programs together--e.g., electrical and mechanical engineering or engineering as part of a general university--and whether there is some scale which results in a minimum cost per semester hour.

As general characteristics, cost relationships in engineering education can be guessed at with reasonable assurance. The figure illustrates what can reasonably be expected. Figure I-1-A shows total cost increasing as a function of scale, but not falling to zero even when scale is very small. Three separate scale-versus-cost curves are identified as a) superior program, b) average program, and c) minimum program. Scale is measured by the number of semester hours of

FIGURE I-1

COST OF ENGINEERING EDUCATION AS A FUNCTION OF SCALE



instruction, which can be translated into other scale variables such as number of graduates, size of admitted freshman class, etc. Figure I-1-B shows how cost per semester hour varies for the minimum program, and similar curves could have been drawn for the superior program and the average program.

There is, in meaningful econometric investigations, the need to formulate estimating equations that are structurally relevant to the matter being investigated. Relevance pertains to the choice of variables and the specific manner of their incorporation into the estimating equation. For example, few would doubt that--ceteris paribus--the cost of education will increase with the average salaries paid teachers. If the staffing, operations and structure of educational establishments were utterly inflexible, the cost of an educational establishment would be a linear function of average salary. But they are not rigid and are adjusted in the interests of cost minimization. Some opportunities are found in the substitution of less expensive resources where there are alternative ways of accomplishing the educational task. The flexibility in quality and characteristics of the educational process is another source of modification--often subtle and seldom made explicit.

A kind of structural change takes place with changes in the scale of operation because some of the resources used in education are not infinitely divisible. Typically manpower is obtainable in units of one--an academic man year of teacher time. If ten teachers were able to teach 250 students last year but, because enrollment is now 275, an eleventh teacher has been hired, there is a structural change arising from the indivisibility of teacher manpower which is reflected in the student-teacher ratio. Indivisibility is serious for small operations, especially where the benefits in functional specialization are important, and the establishment is too small to employ many specialists full time. In higher education specialization results in excessive staff requirements in small departments and schools.

The importance of such considerations suggests that the cost of engineering education should be studied within the framework of a structurally accurate model. The approach of this study is to develop such a model and quantify the parameters and functional relationships as the basis for investigating a large number of cost-impacting factors.

The manner in which the model will be constructed will be highly analogous to the process of engineering design--as it might be applied to an engineering college or engineering curriculum. It is very much the result of looking at the process from the inside--but with an economist's eyes. Specifically, educational programs at several scales of operation will be designed with the requisite facilities and staff.

Standard program characteristics, as for example class size or range of optional subjects, will be postulated. The exercise will be repeated for programs with alternative characteristics in order to establish a cost-versus-program size relationship for the alternatives.

It was long ago discovered in empirical studies in economics that structural cost-versus-scale relationships cannot be established with any precision through the analysis of statistics collected from a sample of organizations. Data can be collected, and a few salient characteristics of each organization can be established. A regression can be fitted to the cost and scale variables with the quantified salient characteristics as additional independent variables, and sometimes good statistical results will be obtained. An enormous amount of statistical analysis of this sort has been done, but for this study the approach is not used.

Engineering education programs actually in existence vary tremendously in characteristics, and while it is difficult to pin down the cost implications of the variations, many would be reflected in cost data that might be obtained from engineering schools. A statistical study of the costs of engineering education in which costs per semester hour were plotted against program size would show a considerable amount of statistical scatter. It would be difficult to obtain a clear picture of the cost-versus-size relationship for constant characteristics--

especially if there were some tendency for program characteristics also to vary with program scale. As one of the principal cost-influencing characteristics is program complexity, which tends to increase with scale, it is quite likely that such a relationship does exist. For this reason, the statistical approach to cost functions has severe limitations. The basic difficulty could be overcome if the number of data were large compared to the number of cost-affecting characteristics that could be varied, but there are not enough engineering schools relative to the number of cost-influencing variables for this approach to be workable (each school produces a single datum).

The proposed engineering approach requires the design of a number of engineering programs, specifying scale, curricula, faculty, facilities, etc. In order for any given functional relationship to be a legitimate constant characteristics curve, considerable care must be exercised in designing the programs of various scales. The type of information which is employed in developing the functional relationship is entirely different from that which would be used in a statistical approach. Much more must be known about the internal design of the engineering educational program, and there must be more reliance on persons who are expert in engineering education. The approach is quite like what would be done if a brand new engineering school were to be established from scratch, with the size of the student body predetermined. Inevitably, judgment influences the selection of facilities and characteristics, as it does in any design exercise.

Although the approach outlined above is relatively common as a basis for cost-function estimation, it has been used to investigate economies of scale in agriculture. Here, statistical approaches have been particularly ineffective.

Although not a statistical approach in the classic sense, the approach used here is not isolated from real-life data. Cost-estimating factors must be derived from actual experience in engineering education. For example, costs will be estimated by assigning salaries which are in line with actual salaries paid in accredited engineering schools. Curricula will be designed along the lines of accredited engineering schools, and class size, library facilities and costs will be based on actual schools.

It must be emphasized that the postulated policies are operating policies and not "results" (e.g., objectives) policies. Thus, one operating policy might be that graduate courses will be taught by persons of associate or full professorial rank paid at the average salary level of ECPD accredited schools with graduate curricula. This is an operating policy with specific cost implications. High salaries might be an efficient way of achieving excellence in engineering education. But the connection between salary policy and excellence is obscure, and there are many roads to excellence.

Obviously excellence has much to do with the ability of a university to attract enough students to operate at a certain scale. However, the classic separation between demand analysis and cost analysis will be maintained. This is a cost study only, although hypothetical revenues obtained if the program can operate at specified levels will be compared with costs of operating at that level. It will not consider whether a particular school, following the policies for which costs are calculated, could actually attract any particular number of students, given certain tuition levels and program characteristics.

II. FACULTY REQUIREMENTS RELATED TO CURRICULA

Ground Rules for the Baseline Program

The principal determinants of faculty requirements are the curriculum which must be taught, the amount of teaching which can be performed by each faculty member, and the number of students. In the approach used here, the minimum possible faculty will be determined as a baseline requirement. Obviously, any college must provide sufficient courses to permit full-time study for four years of college. For an accredited engineering school, this means at least 40 courses and 120 semester hours of work, and no smaller curriculum is possible; such a curriculum is, therefore, a baseline program representing a minimum below which the educational function cannot be performed at all, so that below 40 a functional relationship between curriculum span (as measured by the number of courses or semester hours) simply does not exist.

Similarly, the minimum faculty which could teach this baseline curriculum is the absolute minimum faculty below which the educational function could not be performed. In the curriculum-faculty size relationship, the crucial element is the workload which can be borne by faculty members. As a guideline the AAUP standard faculty load will be used, which limits workload to four preparations and six class meetings per year.

Of course there are colleges which impose heavier loads, but the trend of the times is against them, and the better colleges impose even smaller loads. The baseline load is not an absolute minimum in the same degree as is the 40-subject curriculum. It would be meaningful to explore the cost and quality implications of larger teaching loads and perform a cost-benefit comparison of the incremental reduction in cost with the incremental change in quality. The effect of reduced loads could be examined in a similar way.

Although the number of students per class is sometimes considered to be an element in faculty workload, the AAUP is ambiguous on this point, merely noting that class size and other characteristics affect the arduousness of teaching and that adjustments should be made for difficult courses. Many college teachers and students prefer small classes and feel that the quality of instruction suffers as class size increases. The evidence on this point is not clear, and some studies indicate that, if teaching methods and personnel are appropriate to the larger class size, students learn as much in large lecture classes as in small sections. Clearly, limiting the size of some or all classes can make it necessary to have a larger faculty than would otherwise be the case. In the baseline program the analysis will standardize on a 50-student class size so that several sections must be offered where more than 50 students take a course. It is possible to explore the cost-benefit of smaller as well as larger class sizes. Obviously the minimum number of faculty is determined by the number of courses times the sections taught per course, divided into the workload per faculty member.

Two situations in which engineering education might be performed amount to different baseline conditions. The first is the situation of an exclusively engineering college which offers only engineering degrees and must provide the entire curriculum. Accreditation requires courses in science and humanities as part of an engineering degree program so such a college must provide the faculty for nonengineering subjects. Since the nonengineering requirement is generally met by introductory courses in a rather diverse group of subjects, a strictly engineering college must provide a scattering of faculty among many nonengineering disciplines. This can be a significant burden on a small exclusively engineering college. It is hard for it to use the nonengineering faculty fully, or to provide them with a stimulating variety of subjects to teach.

The baseline program which will be developed here actually provides courses and faculty for only a single set of electives--in effect no electives at all. Engineering education is particularly easy to study because it is typical for the course of study to be almost wholly prescribed. Typically, the student has no electives in the sciences and engineering until his sixth semester. What nonengineering subjects he is permitted to take may be prescribed by university rather than engineering school policy: e.g., beginning English, American History, etc. Obviously more choice for the student is desirable, and it must be part of this study to explore the cost implications of various degrees of choice. However, the whole spectrum of choice which is allowed to undergraduate engineering students, even in colleges which are not striving to limit faculty, is not very great.

The second general situation is the engineering school as part of a large general university, in which science and general education courses are available in the university curriculum. The general educational program is the reason for faculties in the disciplines in which engineering students are required to take nonengineering subjects, and the additional faculty required as a result of the engineering program depends only on the additional teaching load imposed by the engineering student body. In the sciences and mathematics, this may indeed be significant, but elsewhere, the engineering students may be so widely scattered as not to be a distinct consideration in faculty manpower planning; word that the number of engineering students will double will not interest the chairman of the Slavic languages department.

Cost versus size relationships will be established for an accredited baseline program for student bodies ranging from 200 to 3200 engineering undergraduates, for an identical curriculum.

The requisite number of personnel, facilities, etc. and their costs will be calculated for each scale.

Characteristics of the Baseline Curriculum

The specification of a baseline program that will meet accreditation standards is a judgmental thing. Accreditation is performed by committees of the Engineers' Council for Professional Development (ECPD) which has stated policies, procedures and criteria in general terms. Curricula rather than institutions are accredited, and accreditation applies only to the first engineering degree--generally the bachelor's. Qualitative and quantitative factors are considered by a visiting committee. Not all engineering programs of an institution are necessarily accredited. The accrediting of curricula is restricted to institutions that have been accredited by their regional university-college accrediting organization.

Essentially, the content of the curricula must include:

- approximately 2 1/2 years in mathematics, the basic sciences and engineering sciences which amounts to an integrated education experience
- included in the above, at least 1/2 year of mathematics beyond trigonometry, at least 1/2 year of basic sciences, at least 1 year of engineering sciences
- sequential development in the engineering area, including analytical and experimental studies and introduction to engineering methods
- a progression which carries fundamental training in basic science, etc. into the teaching of the latter engineering courses

- breadth of coverage in the engineering which extends into sciences and mathematics
- coverage of all significant portions of a subject where the public may reasonably expect engineers in that subject area to have competence
- a curriculum that develops the ability to apply pertinent knowledge to the practice of engineering
- 1/2 to 1 year in the humanities and social sciences
- additional course work relevant to the engineering program that brings the total up to 3 5/6 years' work so that nonrelevant subjects as law, education, advanced ROTC amount to additional requirements.

In addition to curriculum requirements, programs and institutions are evaluated on the basis of:

- teaching loads
- quality of instruction
- faculty qualifications
- administration, organization and policies
- admission requirements
- physical facilities
- facilities
- financial standing and expenditures of the institution
- number of engineering students as a whole and in the curricula for which accreditation is sought
- curricula offered and degrees conferred
- age of the institution and the curricula
- scholastic work of students
- record of graduates.

There are no explicit statements on how these factors are to be measured, what are minimum standards, or how superior performance in one might be traded off against mediocre performance in another. However, a baseline program can be interpreted from the characteristics of engineering schools that have met accreditation requirements.

Table II-1 summarizes the teaching load requirements generated by a typical accredited curricula in electrical, civil and mechanical engineering. The table presents the course requirements of the three programs separately by academic discipline, giving the number of courses, lecture hours per week, laboratory or recitations per week, and the semester hours of credit, as derived from catalog descriptions. In some cases, a single course combines lecture and recitation or laboratory. Recitations are typically one-hour sessions and laboratories two or more hours. There are also separate exclusively laboratory courses, generally intended to be taken concurrently with some specified lecture course. These are separate courses but courses that combine lecture and lab are, in the course count, one course. The number of technical electives specified is the minimum which would enable students to complete their program, and amounts only to a single set of "electives" in each case. The general education portion also provides a minimum program without alternatives beyond the minimum. There is generally some difference in the specific courses in an

TABLE II-1

TEACHING LOAD IN CURRICULA LEADING TO BS IN ELECTRICAL, MECHANICAL AND CIVIL ENGINEERING, BY ACADEMIC DISCIPLINE

	Electrical				Mechanical				Civil			
	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours
ENGINEERING:												
Engineering Science	5	8	8	12	5	13	2	15	4	10	4	12
Electrical	14	30	5	35	4	6	2	8	1	3	0	3
Mechanical	1	3	0	3	16	29	14	45	1	3	0	3
Civil	0	0	0	0	0	0	0	0	13	32	4	36
Technical Electives in Major	4	12	0	12	3	9	0	9	5	15	0	15
Other Technical Electives	1	3	0	3	0	0	0	0	0	0	0	0
SCIENCES:												
Mathematics	5	15	8	19	4	12	8	16	4	12	8	16
Physics	4	12	5	14	3	9	5	11	3	9	5	11
Chemistry	2	6	2	8	2	6	2	8	2	6	2	8
GENERAL EDUCATION:												
English	3	9	0	9	3	9	0	9	3	9	0	9
Fine Arts/Philosophy	1	3	0	3	1	3	0	3	1	3	0	3
History	2	6	0	6	2	6	0	6	2	6	0	6
Social Sciences	2	6	0	6	2	6	0	6	2	6	0	6
Economics	-	-	-	-	-	-	-	-	1	3	0	3
ELECTIVES:												
Economics, Management or Law	-	-	-	-	-	-	-	-	1	3	0	3
Unrestricted	-	-	-	-	-	-	-	-	1	3	0	3
HEALTH AND PHYSICAL EDUCATION:												
Health Sciences	1	2	0	2	1	2	0	2	1	2	0	2
Physical Education	2	0	2	2	2	0	2	2	2	0	2	2
TOTALS	47	115	30	134	48	110	35	140	47	125	25	141

engineering discipline according to the major; thus, the four courses taken in electrical engineering by mechanical engineering majors include special courses designed for nonelectrical engineering majors. However, most of the science and general education courses are identical regardless of the engineering major.

It will be seen that there is some difference in workload according to the major subject, although somewhat coincidentally the number of courses is 47 in one and 48 in the other.

Because of the common core of engineering subjects taken by all engineering students and the common requirement for all majors in general education (plus health and physical education), the total number of courses required to offer two majors in engineering is not the simple sum of the requirements in each field. How this works out is shown in Table II-2, which shows that electrical with a 47-course program and mechanical with a 48-course program could be covered by a 71-course curriculum. This combined offering would require 199 semester hours of courses in the catalog, of which 134 would be taken by electrical engineering majors and 140 by mechanical engineering majors. Note, however, that holding down the number of required courses originates mainly outside of engineering.

The case of these programs is shown in the last column to the right, for a school offering all three options. It would need to offer 94 courses, of which 69 would be in engineering, worth 265 semester hours of which 187 would be in engineering.

TABLE II-2

TEACHING LOAD IN CURRICULA THAT OFFER CHOICES OF PROGRAMS LEADING TO BS IN ELECTRICAL, MECHANICAL AND CIVIL ENGINEERING, BY ACADEMIC DISCIPLINE

	Electrical & Mechanical				Mechanical & Civil				Electrical & Civil				Electrical, Mechanical & Civil			
	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours	Courses	Lecture Hours Per Week	Laboratory or Recitation Per Week	Semester Hours
ENGINEERING:																
Engineering Science	7	14	8	18	5	13	2	15	6	11	8	15	7	14	8	18
Electrical	18	36	7	43	5	9	2	11	15	33	5	38	19	39	7	46
Mechanical	17	32	14	48	17	32	14	8	2	6	0	6	18	35	14	51
Civil	0	0	0	0	13	32	4	36	13	32	4	36	13	32	4	36
Technical Electives in Major*	4	12	0	12	3	9	0	9	4	12	0	12	4	12	0	12
	3	9	0	9	5	15	0	15	5	15	0	15	3	9	0	9
													5	15	0	15
Other Technical Electives	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCIENCES:																
Mathematics	5	15	8	19	4	12	8	16	5	15	8	19	5	15	8	19
Physics	4	12	5	14	3	9	5	11	4	12	5	14	4	12	5	14
Chemistry	2	6	2	8	2	6	2	8	2	6	2	8	2	6	2	8
GENERAL EDUCATION:																
English	3	9	0	9	3	9	0	9	3	9	0	9	3	9	0	9
Fine Arts/Philosophy	1	3	0	3	1	3	0	3	1	3	0	3	1	3	0	3
History	2	6	0	6	2	6	0	6	2	6	0	6	2	6	0	6
Social Sciences	2	6	0	6	2	6	0	6	2	6	0	6	2	6	0	6
Economics	-	-	-	-	1	3	0	3	1	3	0	3	1	3	0	3
ELECTIVES:																
Economics, Management or Law	-	-	-	-	1	3	0	3	1	3	0	3	1	3	0	3
Unrestricted	-	-	-	-	1	3	0	3	1	3	0	3	1	3	0	3
HEALTH AND PHYSICAL EDUCATION:																
Health Sciences	1	2	0	2	1	2	0	2	1	2	0	2	1	2	0	2
Physical Education	2	0	2	2	2	0	2	2	2	0	2	2	2	0	2	2
TOTALS	71	162	46	199	71	172	39	206	70	177	34	200	94	224	50	265

*Stated in order given in title.

Nonengineering requirements for electrical, mechanical and civil offered alone are 22, 20 and 23 respectively, and to offer the three combined requires only 25 nonengireering courses in the curriculum. There is some reduction in engineering course curricula in offering the three majors jointly, but the major saving is in the common core courses. The larger the core the greater the saving.

The above figures, which apply to the independent engineering college, indicate that the engineering school in a large university does not experience much reduction in course requirements as a result of teaching more than one engineering discipline jointly as compared with each separately and that what reduction is found is in the core subjects of engineering science, which are practically the only engineering courses taken by all majors.

Constraints as Factors in Faculty Workload

The course-load capacity of faculty as recommended by AAUP refers to number of preparations, number of courses, and in general terms to other elements of faculty workload. It recognizes that out-of-class contact with students, administrative duties and research performance are part of the normal work pattern without being specific as to the amount. It is possible to develop more complete explicit statements of workload that are consistent with the AAUP position by estimating the usual requirements on a faculty member.

The revised statement by the Committee in the Spring 1970 AAUP bulletin proposes a maximum for undergraduate teaching of 12 classroom hours per week and six separate course preparations during the academic year, within the traditional 32-week academic year, without unusual expectations in terms of research, administration or counseling, etc. and that fair equivalent workloads be assigned to faculty who supervise laboratories, conduct tutorials, assist beginning teachers, etc. However, the report notes the steady reduction in load "in American colleges and universities noted for the effectiveness of their faculties in teaching and scholarship to norms that can be stated as follows:

- for undergraduate instruction, a teaching load of nine hours per week
- for instruction, partly or entirely at the graduate level, a teaching load of six hours per week."

In summary, the report also says that "extreme differences between courses should not be overlooked...in some subjects the advanced course is more demanding; in others the introductory course...one course may entail constant student consultation; another may entail a heavy burden of paperwork...in a given institution there will be many generally comparable courses, and for these the difficulty will probably be directly proportionate to the number of students involved. In some institutions aware of this problem, faculty workload is now measured in terms of student instruction load, or 'contact hours' as well as the conventional classroom or credit hours." In engineering and the sciences, laboratory courses are common, and the extra work involved--even where the laboratory is supervised by an assistant--is a consideration that is relatively infrequent in other subjects.

Reasonable research expectations are also related to teaching load in the statement, which states that "it is very doubtful that a continuing effort in original inquiry can be maintained by a faculty carrying a teaching load of more than nine hours; and it is worth noting that a number of leading universities desiring to emphasize research have already moved or are now moving to a six-hour policy."

These statements are considered to postulate a set of constraints, viz,

- six preparations per year
- nine class meetings per year
- a total workload including administrative, consulting, research and other duties which does not exceed the normal for a faculty member teaching at the six and nine level plus the other duties.

Thus, the six preparation constraint means that the minimum faculty must be one-sixth of the total number of preparations, and the nine class constraint means that the minimum faculty must be one-ninth of the scheduled classes. If, however, a faculty member meets fewer than nine classes or makes less than six, a load of additional duties beyond the norm could be imposed without exceeding the total normal workload.

Two other constraints seem to be implied by ECPD accreditation standards. One which arises from the position of faculty qualifications is interpreted to mean that a man must be restricted in his teaching assignments to his own discipline. It is obvious that an English professor should not teach a mechanical engineering class, but the criteria are also taken to mean that a professor of electrical engineering should not teach engineering science, mechanical engineering, mathematics, or physics.

The second arises from the inference as to a qualitative criteria for teaching staff. The statement is anything but definite. One can interpret the statement to mean that continuity and stability are considered to be important. The statement that qualitative criteria include intellectual interests, attainments, and professional productivity of the faculty also seems relevant.

I interpret the ECPD views in these matters as implying that there is some minimum faculty in any one discipline--that this is the essential means of providing continuity, stability, and the intellectual stimulus which will enable a faculty to meet ECPD criteria. Only in this way can a faculty member have colleagues in his own discipline.

It is a common opinion that there is some critical number of professionals working together in an organization such as a faculty or a research laboratory, below which the tendency is for quality to decline through lack of intellectual stimulus and loss of the better members, and above which there is the possibility of improvement. These views, not supported by research findings, represent "conventional wisdom." However, they deserve some attention, so I have chosen as an additional constraint that there be at least three faculty members in any discipline which is taught at all. However, I have--somewhat arbitrarily--proposed no minimum for health sciences on the grounds that this would be taught by a doctor of medicine whose colleagual community would be his local medical society, or for physical education.

The minimum-faculty-in-a-discipline constraint significantly influences the findings which follow, since if ten subjects must be taught the minimum faculty is then 30, plus an MD and a physical education instructor. Taken together with the disciplinary constraint it postulates minimum faculties in nonengineering disciplines that--for very small colleges--exceed by considerable margins what is required to teach the limited number but broadly distributed nonengineering courses taken by engineering students.

Functional relationships between faculty numbers and size of student body which are worked out for baseline programs are functional relationships which devolve in a considerable degree from the specific choice of constraints, as just outlined. Of course, these constraints can be relaxed and faculty requirements recalculated by those who prefer some other set of constraints or none at all.

One constraint which critically affects faculty numbers is class size. It has been postulated an upper limit. The basis for this constraint lies primarily in views on quality of instruction, which is commonly believed to depend on class sizes not being too great. However, the importance of class size depends on the subject and the particular aptitudes of the teacher. Certainly many high-quality colleges are willing to teach some subjects--generally introductory subjects--in classes ranging into the hundreds, while insisting on small classes in mathematics, language instruction, etc.

In the baseline program, a maximum class size of 50 is postulated for all classes. Thus, if 100 students are to take a course, the minimum number of sections in which it might be offered is two. No additional constraints arising from scheduling problems, etc. have been considered, and it is assumed that such a minimum is actually feasible with the 50-student constraint. Of course, alternative sets of constraints--e.g., 100 in introductory courses and 25 in advanced classes, etc.--can be used, and it will be of interest to examine the effect of such alternatives on faculty minimum size.

The Workload Constraint

In small schools minimum faculty and the six and nine teaching load constraints are operative, and it is not necessary to be concerned with normal workload constraint. However, in the larger schools the student-faculty ratio reaches numbers in excess of 27 to one and large student numbers mean extra work.

Under these circumstances the workload constraint might be operative, and the faculty minimum would need to be increased to provide necessary manpower for administrative and other duties. Niggardliness in providing administrative and supportive staff below the norm would also generate extra workload for faculty. Exceptional research demands without release from other duties would generate an abnormally high workload.

An estimating formula which may be used to calculate the actual faculty workload from such characteristics is conceptually straightforward. One difficulty is that many activities do not fall in mutually exclusive categories. Estimating parameters can be derived from faculty time surveys taken in conjunction with patterns of performance, and recent studies at Berkeley, as well as earlier studies elsewhere, have grappled with the overlapping categories by separate treatment of time devoted exclusively in single categories and other categories for combinations of activities (e.g., research and thesis supervision) which are performed jointly. Obviously, in a strictly undergraduate program, under consideration here, the categorization problem is simpler than in a more complex context.

The 1968 Faculty Effort and Output Survey of the University of California is one source of estimates of the effort associated with various activities. It is based on responses from

668 faculty members, including 9 and 11-month appointees, some of whom had sabbatical or other leave during the year, and some of whom served as departmental chairmen or had other complicating responsibilities. It found that the average workweek was 60.4 hours during the 10-week period of each quarter when classes were in session, and 58.3 hours for a 39-week period which included registration, examination, and interquarter weeks. This was judged as not inconsistent with other surveys of academic and professional men, and probably to be reasonably accurate. This time was categorized in a matrix, of which some high points are as follows. 21.1 hours per week were spent on regular courses, which at Berkeley are typically two per quarter or six hours per week. Administration took 6.8 hours per week. 18.7 hours per week were spent on scholarship and research. 2.7 were spent on student affairs and 7.3 were devoted to supervision of student independent studies (3/5 graduate thesis supervision). 2.2 were spent on other professional activities (departmental colloquia and professional society activities) and 1.6 to public service and other.

Other results were that, university-wide, to teach six hours per week involved three additional contact hours and 13.9 hours of course preparation. These figures differ by discipline. Engineering reports a 57.8 hour workweek compared with the 60.9 hour university average and 12.1 hours of research compared with the 18.4 hour university average.

Another source is the report by Allan M. Cartter on An Assessment of Quality in Graduate Education, based on responses in early 1964 from 4,008 members of graduate faculties, selected as scholars or administrators, including 509 in the engineering sciences. The respondents' time division for professional activities, although a secondary result, is of interest here. The time division among senior scholars (more than ten years since their doctorate, but not departmental chairmen) was as follows:

Discipline	Instruction (Graduate and Undergraduate)	Research & Writing	Adminis- trative	Other Profes- sional	Other
Electrical Engineering	49%	18%	22%	8%	3%
Mechanical Engineering	45	19	26	9	1
Civil Engineering	42	20	23	14	1
Mathematics	47	28	18	7	-
Chemistry	52	19	19	9	1
Physics	48	23	20	8	1
English	49	23	21	5	3
History	53	20	17	6	3
Economics	48	23	19	9	2
Philosophy	50	28	13	7	1

The results for junior scholars (within ten years of their PhD) were:

Discipline	Instruction (Graduate and Undergraduate)	Research & Writing	Adminis- trative	Other Profes- sional	Other
Electrical Engineering	60%	17%	14%	9%	-%
Mechanical Engineering	60	20	12	8	-
Civil Engineering	56	22	10	11	1
Mathematics	58	27	9	4	2
Chemistry	62	21	11	5	-
Physics	57	29	8	5	-
English	60	19	15	5	2
History	59	25	12	4	1
Economics	57	25	9	8	1
Philosophy	61	22	12	4	2

Because of the strong bias toward administrators, Cartter's "all respondents" percentages are not considered useful for present purposes, as they include an excessive proportion of departmental chairmen, etc. The three categories (chairmen, senior scholars and junior scholars) can be reweighted based on the Engineer's Joint Council report on Professional Income of Engineers distribution of respondents in engineering colleges by years since baccalaureate degree. That report obtained data from 4310 holders of PhD's in engineering colleges, of which 2179 or 50% were 14 or more years beyond their BS (taken as the nearest break point to ten years beyond the PhD). I think that chairmen must be drawn almost entirely from this latter group, and that there is about one chairman for every 15 faculty members. So the weights might be:

Chairmen	287	6.7%
Other Senior Faculty	1892	43.9
Junior Faculty	2131	49.4
TOTAL	4310	100.0%

Applying these weights to the Cartter data, the following distributions, which differ from the simple averages which he reported for all respondents, are produced:

Discipline	Instruction (Graduate and Undergraduate)	Research & Writing	Adminis- trative	Other Profes- sional	Other
Electrical Engineering	52.6%	17.0%	20.4%	8.6%	1.4%
Mechanical Engineering	50.9	18.8	21.0	8.6	0.6
Civil Engineering	48.3	20.2	18.1	12.3	0.9
Mathematics	51.2	26.7	15.7	5.4	1.0
Chemistry	55.4	19.5	17.1	7.0	0.5
Physics	51.4	25.4	15.9	6.4	0.9
English	53.2	20.1	20.1	5.0	2.4
History	55.0	22.4	15.9	4.9	1.9
Economics	51.3	23.6	15.6	8.4	1.4
Philosophy	55.0	24.4	13.7	5.4	1.5

We can assume that the total time spent is the same for all ranks, although John E. Stecklein's report How to Measure Faculty Work Load shows that at his "College A" professors reported 54.9 hours per week, associates 54.7, assistants 53.8 and instructors 48.0 hours per week. It must be noted that some of the EJC reportees undoubtedly work for nonacademic affiliated laboratories (some data may be available from National Science Foundation reports). The Berkeley report notes a National Academy of Sciences study covering 1940 to 1953 that reported that scientists employed in academic institutions consistently worked about five hours a week more than did their colleagues in nonacademic jobs, but what would be found for those in nonacademic research institutes associated with universities is problematical.

Cartter supplies no estimate of total faculty hours, but using those which are most appropriate from the Berkeley study and applying the above percentages to them produce the following:

Discipline	Hours/Week	Instruction Associated Hours/Week	Most Comparable Berkeley Data
Electrical Engineering	57.8	30.4	33.5
Mechanical Engineering	57.8	29.4	33.5
Civil Engineering	57.8	27.9	33.5
Mathematics	57.0	29.2	25.7
Chemistry	60.4	33.5	30.8
Physics	60.4	31.0	30.8
English	63.4	33.7	32.6
History	60.9	33.5	30.6
Economics	60.9	31.2	30.6
Philosophy	63.4	34.8	32.6

The last column gives the most comparable Berkeley data. The differences are not excessive, and there is an evident similarity in the variation in the two sources. History was considered as a social science, but the agreement would have been better if it had been compared to arts and letters, as were English and philosophy.

This agreement gives support to using the Berkeley data for distribution of instructional time between course-related work and supervision of independent research, as follows (these data are included in total instructional time):

	Course Contact (hours per week)	Course Preparation (hours per week)	Course Total	Course & Independent Study Total
Engineering	8.6	13.3	21.9	33.5
Mathematics	8.2	11.5	19.7	25.7
Physical Sciences	6.4	10.9	17.3	30.8
Arts and Letters	10.8	16.5	27.3	32.6
Social Sciences	9.2	14.5	23.7	30.6
University-Wide	9.0	13.9	22.9	31.3

It is not clear whether Stecklein's data include time for supervision of independent research and student consultation. If his have a two-course, three-hour-per-course load, he would be stating that they devote 41 hours a week to teaching activities. This would indeed be compatible with his data (though for another year but for the same college) that the average workweek is 52 hours, of which 8.6 were other activities, including 6.3 for research. Obviously "College A" is not a research-oriented institution, and there is not likely to be much research involvement by students if there is not much by the faculty.

It would be dangerous to assume that six classroom hours were the standard in all these departments, since two, six and four hours are not uncommon, and there is a problem with laboratory courses.

The Cartter data refer to all teaching done by graduate faculties. Stecklein reports for his "College A" the teaching time activity per clock hour of instruction which--for all faculty--runs 6.65 for lower division undergraduate courses, 6.35 for upper division undergraduate courses and 7.89 hours for graduate courses. Except for full professors teaching undergraduates, there is, for any level of instruction, a decrease in preparation time as the rank of the instructor increases. Possibly the full professors who teach lower division classes are generally giving very large lecture courses.

Development of a Workload Formula

The present interest in these data is a) to use them as a basis for calculating how much faculty time is available for nonteaching duties when the class-meeting load or the course-preparation load is reduced below the AAUP minimum and b) to establish workload equivalencies for larger-than-average classes or administrative assignments.

Referring to the data on page II-22, it will be seen that the average number of contact hours amounts to nine. This includes contact in class, in laboratories, field trips, and consultations with students. Time spent in class and formal class activity such as laboratories and field trips can be expressed as proportionate to the total number of classes, so, where some coefficient is the average number of such hours per course, the total time spent is that coefficient times the average number of classes per faculty member. The amount of student consultation time depends on whether there are teaching assistants to undertake the bulk of student contact, and therefore a distinction should be made between courses in which there are and are not TA assistants. Thus:

$$H(C) = a_1[N(NC)+N(SC)] + b_1N(SNC) + c_1N(SSC)$$

where

$H(C)$ is contact hours

$N(NC)$ is the number of classes taught without assistance

$N(SC)$ is the number of classes taught with TA assistance

$N(SNC)$ is the number of students in classes taught without assistance

$N(SSC)$ is the number of students in classes taught with TA assistance.

Of course, the sum of N(NC) and N(SC) is the total number of classes so the coefficient "a" relates to the total number of classes taught, while "b" relates to the average number of students in classes taught without assistance and "c" to the average number in classes taught with assistance. The average number of students in assisted and unassisted classes will differ, of course. The coefficient b is the contact time required by a student in an unassisted class and c in an assisted class.

Preparation hours are similarly a mix of activities. Some are in the nature of a re-useable investment and the remainder are expended in the actual conduct of a course. Each subject requires a basic preparation, and the investment in selecting a text, preparing a reading outline and lecture notes need not be wholly repeated each time the course is offered, but updated periodically. Review and organizational activities, arranging for availability of reading material, lining up and training teaching assistants, writing, grading or supervising the grading of tests are largely expendable and must be repeated every time.

Thus, some part of preparation time is related to the number of subjects taught (including an average portion of first-time preparation). Preparation time for nonassisted subjects and assisted would differ, because of the time associated with TA's and, being larger lecture courses, they tend to be more intensively prepared.

Expendable preparation time where the faculty members deal with students directly (grading exams and term papers themselves), and where they deal with them through teaching assistants (who grade exams) etc., are separate cases. Directly taught courses impose a substantial load according to the number of students, while indirectly taught courses a lesser load per student, plus a load per teaching assistant. Thus, for each course there is a preparation, etc. load which is independent of the number of students and another portion which depends on it. Thus, an estimating equation can take the form:

$$H(P) = a_2N(S) + b_2N(NC) + c_2N(SC) + d_2N(SNC) + e_2N(TA)$$

where

$H(P)$ is preparation hours

$N(S)$ is the number of subjects prepared

$N(NC)$ is the number of classes taught without assistance

$N(SC)$ is the number of classes taught with TA assistance

$N(SNC)$ is the number of students in classes taught without assistance

$N(TA)$ is the number of teaching assistants.

All of the above are seen as averages, and the value of $H(P)$ for the California system is 13.9 hours.

The California study noted that the typical course load was two, and the hours in class were six. Thus, six is a working estimate for the coefficient a_1, and a working estimate for the sum of the coefficients b_1 and c_1 is nine minus six, or three. No breakdown is supplied of the proportion of nonassisted and assisted classes.

One might hypothesize as to what the numbers might be. There are about 98,780 students and 5,871 faculty in the University of California system. If students take an average of four courses at a time, 395 thousand courses are taught by the faculty, and if faculty teach two at a time, average class size must be about 335. Since there is a large number of very small classes, some must be very large indeed.

These two expressions can be added directly to obtain a combined expression for the workload associated with teaching, which would relate it to the number of subjects N(S), the number of courses N(NC) + N(SC), the number of students N(SNC) + N(SCC), the number of teaching assistants supervised N(TA) as follows:

$$H(C) + H(P) = a_2N(S) + (a_1+b_2)N(NC) + (a_1+c_2)N(SC) + (b_1+d_2)N(SNC) + c_1N(SSC) + e_2N(TA)$$

It can be used to estimate the workload associated with various mixes of course preparations and class meetings, and to identify the amount of time available for other duties through a reduction in preparations below the AAUP standard

This difference between normal teaching time and actual teaching time as determined by the formula will be called "slack time." It is, expressed in hours per week, time which the college can ask the faculty to use for appropriate other duties, such as academic administration, research, etc. without increasing the total workload above the AAUP norm.

It would be premature to develop these numbers with the data now at hand. For illustrative purposes, consistent with numbers which will be used later, the following averages will be assumed for California:

number of preparations - 2

number of classes - 2
  without assistance - 1
  with assistance - 1

number of students
  in classes without assistance - 50
  in classes with TA assistance - 150

number of teaching assistants - 3

Rounding from a total teaching time of 22.9 to 23.0 hours, a consistent and plausible formula for teaching time in the format of the above equation would be:

$$H(C) + H(P) = 5N(S) + 3(NC) + 3.5(SC) + .04(SNC) + .01(SSC) + 1.0(TA)$$

That is to say, preparation time per subject is five hours per week; in-class performance plus contact time, etc. for a course taught directly is 3.0 hours per week; and for a course taught through teaching assistants 3.5 hours (typically two lectures by the course leader and one meeting with TA's). The coefficient associated with students taught directly, which reflects consultation, exam grading, etc. is .04 hours per student per week or two hours for a 50-student class. However, for students taught indirectly the coefficient is .01 or 1.5 hours per week for 150 students. One hour a week is spent with each teaching assistant.

Workload Standards from the Formulae

Under the circumstances reflected in the California survey and with the assumptions given above, ten hours a week are spent on the 50-student class and 13 hours on the 150-student class. However, if the 150-student class were taught directly instead of with teaching assistants, it would have taken 14 hours per week. Thus, there is a slight time saving through the use of TA's, and the saving would increase with even larger class sizes. It should be re-emphasized that these coefficients are purely hypothetical.

The California teaching load is lower than the AAUP criteria, reflecting the above average research commitments of its faculties. Using the formula derived from Berkeley data, the AAUP standard load can be translated into hour equivalents. Substituting into the formula two preparations and three classes, one of which is assisted and the same class sizes and numbers of assistants, the time for teaching would be 28 hours. To make two preparations and meet three 50-man classes, with no need to prepare TA's would, require only 25 hours. Thus, the extra work involved in including one 150-man class with three teaching assistants is three hours per week.

The figure of 25 hours a week as determined by the above formula will be taken as the AAUP normal load. To handle a course with three TA's would require relief of nonteaching duties equivalent to three hours a week. Faculty time for nonteaching duties can be obtained by reducing the number of subjects prepared or the number of classes met, or both. For example, using the above formula, to meet three classes of 50 based on the same preparation, without assistance, would require 20 hours a week, and to meet two classes with one preparation would require only 15 hours a week, which can be compared with the normal load of 25 hours to find out how many additional hours would be available for other duties.

III. THE ACADEMIC WORKLOAD
FOR AN ELECTRICAL ENGINEERING COLLEGE

Size of Student Body and Number of Faculty Required

The inflexibility of the undergraduate engineering program makes it particularly easy to relate class size to the total number of students. If 50 students are admitted in each class, if there is no attrition, and the school has achieved a stable entry rate, every required subject will have 50 registrants. If each subject is taught only once, the total number of class preparations and hence the required faculty is as indicated above.

The simplest case for which faculty requirements can be calculated as a function of size of student body, subject to the various constraints already described, is that of a hypothetical engineering school not part of a greater university, offering only a single major, and including in its curriculum only the absolute minimum number of courses necessary for completion of the undergraduate degree program.

At the undergraduate level, there is a single curriculum with absolutely no electives during the entire four-year program. The total number of semester hours taken by each student in four years is 120. Thus, if 100 students are admitted--with compensation for losses through transfers--every class in the entire four years has 100 students. A program that has achieved stability at that level would teach 6,000 semester hours of instruction per semester to a total of 400 students (100 in each of four classes), assuming that students take 15 semester hours of instruction at all times.

The faculty size will be calculated for an autonomous engineering college, which must, of course, provide faculty for the nonengineering subjects which are essential in an accredited program.

Next, an engineering school which is part of a general university will be examined. The effects of offering broader programs for undergraduates, combined graduate and undergraduate programs, and combinations of instruction and research will be examined in later sections.

Table II-1--in the preceding chapter--summarized course content of a program of study leading to a BS in electrical engineering. As is typical, the freshman and sophomore years concentrate on mathematics, the basic sciences, and certain "core" engineering subjects, and it is not until the junior year that students are principally engaged in electrical engineering courses. In the following exercise, laboratory and recitation sections are temporarily ignored. The requirements for teaching and laboratory assistants will be estimated separately.

A 40-course program, distributed by subject area, is shown in the first column of Table III-1. The rest of the table shows the minimum faculty as a function of total college

TABLE III-1

MINIMUM FACULTIES FOR COLLEGES OFFERING ONLY A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, AAUP FACULTY LOAD, 50-STUDENT CLASS SIZE LIMIT, SEMESTER PLAN EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS

Subject Area	Number of Subjects	Number of Students					
		200	400	600	800	1600	3200
Engineering							
Electrical	12	3	4	6	8	16	32
Engineering Science	3	3	3	3	3	4	8
Mechanical	2	3	3	3	3	3	6
Sciences							
Mathematics	6	3	3	3	4	8	16
Physics	4	3	3	3	3	6	11
Chemistry	2	3	3	3	3	3	6
General Education							
English	3	3	3	3	3	4	8
Fine Arts/Philosophy	1	3	3	3	3	3	6
History	2	3	3	3	3	3	6
Social Sciences	2	3	3	3	3	3	6
Health and Physical Education							
Health	1	1	1	1	1	2	3
Physical Education	2	1	1	1	1	2	3
TOTAL	40	32	33	35	38	57	111

enrollment. In every case the number of faculty is the result of the constraints which are operative with a student body of the size specified, ranging from 200 students--or 50 admittees per year--to 3200 students--or 800 admittees per year. Every course has precisely 50 students. It is assumed that drop-outs and other losses are exactly replaced by students transferring in, so senior level classes as well as freshman classes have 50 students.

With a 200-student enrollment, the three-member minimum faculty is the operational constraint for all departments except electrical engineering. If student enrollment goes up to 400, faculty in electrical engineering must increase. As the student body increases to 800 students, mathematics, the subject area with the next largest number of courses, must increase its faculty, followed by English at the level of 1600-student enrollment. With a 3200-student enrollment, the minimum size faculty constraint has disappeared for all disciplines.

Because of the operation of these constraints, the minimum faculty is never less than 32 for a 40-subject, 12-discipline curriculum, and it increases very gradually up to the 800-subject level. Beyond that, it increases almost linearly with student body size.

Generally, there are a number of ways in which the minimum number can be allocated among the required subjects. As a straight linear programming solution, it is possible to identify that allocation that will minimize the number of subject preparations, and therefore generate the most slack time for other purposes. The usual solution is (subject to the constraint of six class meetings per man) to have all sections of one course taught by the minimum possible faculty by not splitting the sections among more faculty than necessary, and then allocating courses among faculty so that teaching load constraints are not exceeded. There may not be a unique maximum slack solution.

This program identifies two kinds of slack capacity: course preparation capacity and section meeting capacity, by faculty member and discipline. Some slack results from the indivisibility of the one-man unit of faculty, and the rest from the operation of other constraints. Thus, with small enrollments, preparation capacity and the three-man minimum per discipline are the effective constraints, but with larger enrollments the class meeting capacity tends to determine minimum faculty.

Because the three-man minimum plays such an important part in faculty and slack levels in small colleges, it is of interest to see how faculty requirements would be affected by omitting this constraint. Table III-2 shows that without any disciplinary or minimum size constraint the 200-student college could get by with a ten-man faculty. With the disciplinary constraint but no minimum faculty size, it would need a total

TABLE III-2

SUMMARY OF FACULTY REQUIREMENTS OF COLLEGES OFFERING ONLY A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR WITH MINIMUM FACULTY, AAUP FACULTY LOAD STANDARD,* 50-STUDENT CLASS SIZE LIMIT, SEMESTER PLAN, EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS

Characteristic	Number of Students					
	200	400	600	800	1600	3200
Number Students, Entering Class	50	100	150	200	400	800
Average Course Size of Required Subjects	50	100	150	200	400	800
Minimum Number Sections Per Course, with 50-student limit	1	2	3	4	8	16
Minimum Total Number of Section Meetings, 50-student limit	40	80	120	160	320	640
Minimum Faculty - No Disciplinary Constraint (AAUP Load)	10	10	20	27	54	107
Minimum Faculty - Disciplinary Constraint (AAUP Load)	15	15	22	30	57	111
Minimum Faculty - Disciplinary Constraint & 3-man Minimum (AAUP Load)	32	33	35	38	57	111
Preparations (MF-DC-3MM)						
Available:	128	132	140	152	228	444
Needed:	40	40	40	47	80	129
Excess:	88	92	100	105	148	315
Class Meetings (MF-DC-3MM)						
Available:	192	198	210	228	342	666
Needed:	40	60	120	160	320	640
Excess:	152	138	90	68	22	26
Student/Teaching Faculty Ratio (MF-DC-3MM)	6.2	12.1	17.1	21.0	28.1	28.8

*The AAUP standard load is 4 preparations and 6 class meetings per 2-semester academic year.

of 15. The three-man minimum raises the requirement to 32. However, as enrollment increases, the effects of these constraints are largely reduced. With the 800-student enrollment, even without the disciplinary and minimum faculty constraint, a 27-man faculty would be needed. The disciplinary constraint adds only three and the three-man minimum adds another eight. With larger enrollments the class meeting capacity constraint is of overriding importance.

The bottom part of this table presents preparation capacity and class meeting slack capacity separately, given the total array of constraints. It will be seen that in the small college there is a considerable excess of preparation and class meeting capacity, and that as the size of the student body increases the excess preparation capacity increases sharply, while the class meeting capacity declines to the point where it moves irregularly as a result of discontinuities from the one-man minimum unit of faculty.

The last line in the table presents the ratio of students to teaching faculty. The ratio levels off at about 28 with student bodies of 1600 or more. This is a potentially important finding. It should be recalled that this ratio is obtained with teaching loads of only six hours per semester and classes that do not exceed 50 students. At the 1600-student level, 57 faculty are required to make only 80 preparations or an average of 1.4 preparations per faculty member. This load is substantially below the AAUP criteria in an important respect. It shows that it is possible through curriculum design and faculty assignment policy to present an accredited curriculum with a high student-faculty ratio.

The Engineering College in a General University

The isolated engineering-only college or university is relatively rare. Most engineering schools are part of general universities that offer curricula which permit majoring in a wide array of subjects--including all of those in which an engineering undergraduate would be required to take courses as part of his general or scientific education. Minimum faculties in these disciplines are determined by the requirements for departmental majors and service courses requirements. It is often not realized how large a portion of course enrollments in many departments are of service courses; not uncommonly it exceeds two-thirds. Minimum faculty staffing thus tends to be dominated by the service course teaching, but, being introductory, the required disciplinary competence is not great. An ability to handle specialized advanced subjects, with the introductory course teaching load thrown in to round out the teaching load, may be the guide to faculty selection.

The faculty load imposed by engineering students in the general university may be nearly zero--a situation that would be approximated where the number of engineering students was

2

too small to require adding extra sections or courses. Excess classroom capacity is very common in universities. Using the faculty time formula to calculate additional faculty teaching time, only the coefficients associated with numbers of students taught directly and indirectly would enter into the calculation.

Without making assumptions as to the actual class size and class size constraints in the general university, it is difficult to arrive at a figure for the number of additional preparations that should be assumed, and which should enter into the teaching time calculation. It will be assumed that wherever a specific course is required of engineering students that there will be an extra class meeting for every 50 engineering students and that for every six class meetings an extra preparation will be made. On this basis, teaching time will be calculated.

Table III-3 shows the faculty workload generated by engineering students outside of the engineering area, as a function of the size of the engineering enrollment, taking account of the proportion taught, directly and indirectly. Since 25 hours is the normal teaching time, the additional number of faculty has been calculated by dividing total time by 25. In general, the increases would be heavily concentrated in disciplines which are specified as requirements--for example sciences, English, history, health and physical education. The table probably fully states the increased requirement. In a few

TABLE III-3

ADDITIONAL TEACHING WORKLOAD GENERATED IN A GENERAL UNIVERSITY BY ENGINEERING STUDENTS, 50-STUDENT CLASS SIZE LIMIT, IN FACULTY ACADEMIC MAN-YEAR EQUIVALENTS,* 200 to 3200 ENGINEERING STUDENTS

	Number of Engineering Students					
Discipline	200	400	600	800	1600	3200
Science						
Mathematics	.2	.4	.6	.8	1.7	3.4
Physics	.2	.4	.6	.8	1.6	3.1
Chemistry	.1	.2	.2	.3	.6	1.2
General Education						
English	.2	.5	.7	.9	1.9	3.7
Fine Arts/Philosophy	.1	.2	.3	.4	.9	1.8
History	.2	.3	.5	.6	1.3	2.6
Social Science	.1	.2	.3	.4	.9	1.8
Health & Physical Education						
Health	.1	.2	.2	.3	.6	1.3
Physical Education	.2	.4	.4	.6	1.2	2.6
TOTAL	1.4	2.8	3.8	5.1	10.7	21.5

*Number needed where 25-hour per week in teaching preparation and student consultation is normal load.

cases, such as fine arts, philosophy, and the social sciences, there is a broad range of courses open to the engineering students. The occurrence of near-zero increases from engineering is much greater. Of course, zero-cost increases are much less likely when engineering enrollments are very large.

The principal difference between faculty requirements of the isolated engineering college and the engineering school in the general university is that the burden of supporting minimum faculties in little-used disciplines is not a consideration in the latter case. If the teaching load in English from engineering students is one faculty member spread out among several courses, there is a cost saving for engineering education of the cost of two faculty members in English. It is possible to calculate the economies to engineering education from the university association, and they would be especially great with very small engineering enrollments.

Some details of the situation within the engineering school in a general university are given in Table III-4. With no disciplinary constraint within engineering, only a five-man faculty would be required to teach a student body of 200 electrical engineer majors. As this program includes three engineering disciplines (electrical, mechanical and engineering sciences) the minimum faculty under the minimum faculty constraint is nine. But even with a student body of 800, only a 14-man faculty in three engineering disciplines would be needed. As would be expected, there is excess preparation capacity at all levels, but very little excess class meeting capacity except for the 200-student college.

TABLE III-4

SUMMARY OF CHARACTERISTICS OF AN ENGINEERING SCHOOL IN A GENERAL UNIVERSITY OFFERING ONLY A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, AAUP FACULTY LOAD STANDARD, 50-STUDENT MAXIMUM CLASS SIZE, SEMESTER PLAN, EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS

	Number of Students					
Characteristic	200	400	600	800	1600	3200
Number of Students, Entering Class	50	100	150	200	400	800
Average Course Size of Required Subjects	50	100	150	200	400	800
Minimum Number of Sections Per Course with 50-Student Limit	1	2	3	4	8	16
Minimum Faculty - No Disciplinary Constraint within Engineering	5	6	9	12	23	46
Minimum Faculty - Disciplinary Constraint	5	6	9	12	23	46
Minimum Faculty - Disciplinary Constraint and 3-Man Minimum	9	10	12	14	23	46
Preparations (MF-DC-3MM)						
Available:	20	24	36	48	92	184
Needed:	17	17	17	21	34	56
Excess:	3	7	19	27	58	128
Class Meetings (MF-DC-3MM)						
Available:	30	36	54	72	138	276
Needed:	17	34	51	68	136	272
Excess:	13	2	3	4	2	4

Recitation-Quiz Section Workload

In addition to lectures, many courses include recitation or quiz sections or laboratory sections. The usual practice is for such sections to be smaller than lectures. Often the reason is pedagogical--the opportunity for a more direct and less structured interchange between students and an instructor, and because of the limited experience of the teaching assistants who usually conduct such sections. With laboratories, it is also necessary to hold down the number of students in order to economize on the amount of equipment. There is indeed a tradeoff between number of laboratory sessions and laboratory section size in that less equipment must be purchased if there are more sessions. In one semester course a student might use 12 distinct equipment set-ups. Operating in two-man teams, a lab could accommodate 24 students at a time. Using a lab several times a week, a single version of each set-up would be suitable for a large number of students. Scheduling problems may limit the use of laboratory set-ups to afternoons--five times a week (or six including Saturday mornings).

Sections require additional personnel and supervision from the faculty. Faculty supervision was introduced into the faculty workload formula, and the amount of assistant time, and hence the number of such assistants, will now be estimated.

Recitation and quiz sections must be conducted by personnel who may be junior in standing but have essentially the same academic qualifications as the faculty. Typically they are graduate students working on a part-time basis. The postulated undergraduate-only engineering college would not have such personnel available. One way of looking at this is that the availability of graduate students constitutes one of the economies of running a graduate program jointly with an undergraduate program. For our example, one possible assumption might be that the requisite personnel would be available elsewhere--and it is not uncommon for graduate students in one university to find part-time employment as teaching assistants in others which do not have an adequate number of graduate students. Such an assumption would seem to violate the autonomy which has been part of the model. An alternative is to assume that the college would have to employ full-time teaching assistants, or use regular faculty for discussion sections. If these were the options, a college would probably actually alter its policy on discussion sessions, but ruling this out as violating the ground rules of the model, it would first use slack faculty time, and then employ TA's as necessary.

It will be assumed that discussion and recitation sessions are limited to 25, so that the number of discussion groups is twice the number of courses with 50-student enrollments. Groups meet once or twice weekly.

The workload which can be assigned to a teaching assistant is not covered by AAUP standards. It is common to consider two section meetings a week a half-time load--taking into account preparation, quizzes, examinations, attending lectures with the students, etc. The full-time load of four meetings a week which this implies is less than the AAUP load of two preparations and three class meetings, which generally amounts to nine class meetings per week. In the following, it will be assumed that six section meetings per week is the standard for a full-time teaching assistant.

With respect to using full-time faculty for recitation and quiz sections, three sections or recitation sections will be considered equivalent to one unit of class meeting capacity. A slack of one class-meeting capacity is equivalent to three classroom hours per week, or meeting three one-hour recitation sections.

Table III-5 presents the number of one-hour recitation or quiz sections per week for each department which would need to be scheduled in the 40-course curriculum. At the bottom of the table is given the number of teaching assistants that would have to be hired on a full-time basis if all recitation sections were conducted by TA's.

However, before hiring additional personnel a college would use slack capacity available from the regular faculty. The relevant capacity is class-meeting capacity, since sections are assumed to be related to courses for which the faculty member has made a preparation (in any event, he would need to prepare instructions for the TA's).

TABLE III-5

RECITATION AND QUIZ SECTION REQUIREMENTS OF COLLEGES OFFERING A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, 25 STUDENT MAXIMUM PER SECTION, SEMESTER PLAN, 200 to 3200 STUDENTS

		Number of Students					
		200	400	600	800	1600	3200
		Enrollment and Structure					
Per Subject:							
Students		50	100	150	200	400	800
Lecture Sections		1	2	3	4	8	16
Recitation Sections		2	4	6	8	16	32
	Recitation/Quiz Sections in Curriculum	Number of Recitation or Quiz Sections					
Engineering							
Engineering Science	2	4	8	12	16	32	64
Science							
Mathematics*	8	16	32	48	64	128	256
Physics	3	6	12	18	24	48	96
Chemistry	2	4	8	12	16	32	64
General Education							
English	1	2	4	6	8	16	32
History	1	2	4	6	8	16	32
Social Science	1	2	4	6	8	16	32
		Minimum Teaching Assistants on Full-Time Basis					
Engineering							
Engineering Science	1	1	2	2	3	6	11
Science							
Mathematics	2	3	6	8	11	22	43
Physics	1	1	2	3	4	8	16
Chemistry	1	1	2	2	3	6	11
General Education							
English	1	1	1	1	2	3	6
History	1	1	1	1	2	3	6
Social Science	1	1	1	1	2	3	6
TOTAL Full-Time TA's	8	9	15	18	27	51	99

*meet twice weekly

The ability of the college to reduce the need for TA's through the use of this slack is shown in Table III-6. At the top of the table, the slack available by department is given--the class-meeting capacity which appeared in Table III-2 multiplied by three. Subtracting this from the required number of recitation sections gives the number of sections for which TA's must actually be employed, presented in the middle of the table. At the bottom of the table is presented the number of full-time TA's needed after faculty slack time has been used to reduce the requirement.

This table shows that faculty slack time for recitation sections greatly reduces the need for teaching assistants with small enrollments, but with enrollments of 1,600 or more students there is little reduction. The reason is that with large enrollments there is very little slack class-meeting time available from the faculty.

Laboratory Section Workload

Engineering and science are subjects in the curriculum which have laboratories. Sometimes a laboratory session is part of a course, and sometimes there is a separate laboratory course, often closely associated with some other course. In the latter case, the laboratory, as an adjunct of the lecture course, is generally under the supervision of the lecture course instructor.

Equipment and the "span of attention" of a lab assistant determine maximum number of students in a lab session, and

TABLE III-6

TEACHING ASSISTANT REQUIREMENTS OF COLLEGES OFFERING A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, 25 STUDENTS PER SECTION, SEMESTER PLAN, AFTER SLACK FACULTY CLASS-MEETING CAPACITY HAS BEEN UTILIZED

	Number of Students					
	200	400	600	800	1600	3200
	Available Slack Capacity from Faculty in Recitation Units (3 times slack class meeting capacity)					
Engineering Science	45	36	27	18	0	0
Mathematics	36	18	0	0	0	0
Physics	36	30	18	6	12	6
Chemistry	48	42	36	30	6	12
English	45	36	27	18	0	0
History	48	42	36	30	6	12
Social Science	48	42	36	30	6	12
	Recitation or Quiz Sections for Which TA's Must be Employed*					
Engineering Science	0	0	0	0	32	64
Mathematics	0	14	48	64	128	256
Physics	0	0	0	18	36	90
Chemistry	0	0	0	0	26	52
English	0	0	0	0	16	32
History	0	0	0	0	10	20
Social Science	0	0	0	0	10	20
	Adjusted Minimum Teaching Assistants on Full-Time Basis					
Engineering Science	0	0	0	0	6	11
Mathematics	0	3	8	11	22	43
Physics	0	0	0	3	6	15
Chemistry	0	0	0	0	5	9
English	0	0	0	0	3	6
History	0	0	0	0	2	4
Social Science	0	0	0	0	2	4
TOTAL	0	3	8	14	46	92

*e.g., after faculty slack class-meeting capacity has been utilized therefore the number of sessions, given total course enrollment. To make the translation from number of sessions to manpower, information is needed on the number of hours of time available per assistant and the amount of time taken by each laboratory session. In place of solid information the assumptions will be made that laboratory assistants are technicians who work a 40-hour week. It is assumed that they are specialists in a given discipline. They can be employed only on a full-time basis. Their duties are considered to include general demonstration of equipment, assistance to students and supervision during lab periods, advance preparation and maintenance of the equipment. It is assumed that they are year-round employees with summers occupied in equipment overhaul and preparation of new equipment set-ups for student experimentations. Grading lab reports, an academic task, is considered to be included in faculty or TA teaching time and not a duty of lab assistants.

A typical laboratory session runs from two to three hours, so with advance preparation and clean-up time, conducting a lab session should take half a day, and a lab assistant should be able to handle ten sessions per week, provided that labs can be scheduled for the morning.

As it will be assumed that 25 students are the limit for laboratories, the number of lab sessions will be twice the number of class meetings (of 50 students each) with lab sessions. These are: chemistry--first and second semester courses each have one three-hour lab per week; two general physics courses each have one three-hour lab per week; two engineering science courses each have two hours of lab per week; five electrical engineering courses each have one two-hour lab per week; one mechanical engineering course has one two-hour lab per week.

Table III-7 presents the total number of lab sessions and the requisite number of lab assistants as a function of size of student body. Since five different disciplines have lab courses, the minimum number of lab assistants is five. The number increases rather slowly as the student body increases up to 800 students, beyond which the increase is essentially proportionate to the size of the student body. It is a by-product of the student body sizes chosen for the table that there is never any slack lab assistant time in the electrical engineering department; elsewhere when enrollment is small the slack time is considerable. This exactly parallels the situation with faculty.

Administrative Workload on Faculty

The Cartter report and the California survey show that a substantial portion of the time of faculty are normally taken

TABLE III-7

LABORATORY ASSISTANT REQUIREMENTS OF COLLEGES OFFERING A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, 25 STUDENT MAXIMUM PER LABORATORY SECTION, SEMESTER PLAN, 200 to 3200 STUDENTS

		Number of Students					
		200	400	600	800	1600	3200
		Enrollment and Structure					
Per Subject:							
Students		50	100	150	200	400	800
Lecture Sections		1	2	3	4	8	16
Lab Groups		2	4	6	8	16	32
	Laboratory Sessions in Curriculum	Number of Laboratory Sessions					
Engineering							
Electrical	5	10	20	30	40	80	160
Mechanical	1	2	4	6	8	16	32
Engineering Science	3	6	12	18	24	48	96
Sciences							
Physics	2	4	8	12	16	32	64
Chemistry	2	4	8	12	16	32	64
		Minimum Number of Laboratory Assistants					
Engineering							
Electrical		1	2	3	4	8	16
Mechanical		1	1	1	1	2	4
Engineering Science		1	2	2	3	5	10
Sciences							
Physics		1	1	2	2	4	7
Chemistry		1	1	2	2	4	7
TOTAL Lab Assistants		5	7	10	12	23	44

up with administrative duties. Thus, the performance of administrative duties does not per se require reduction in teaching load in order to stay within AAUP criteria; only where these duties are above normal is a reduction needed. It must be presumed that the administrative load which falls upon faculty when the usual number of administrative personnel are supplied, and the student-teacher ratio is normal, is in fact the normal administrative load which AAUP had in mind and that an unusual load is generated only by unusual conditions.

It is not generally appreciated that the time spent on administration by a departmental chairman is a relatively small part of the total time spent on administration in a department--commonly less than 20%. Since this is a surprising conclusion, it may be worth explaining the manner in which it was reached. The Cartter report gives the percentage of faculty time spent on administration by chairmen, senior and junior scholars. Using the EJC distribution as before, and again assuming one chairman per 15 faculty members to determine weights, it would appear, for three engineering disciplines, that the portion of total faculty time which is used for administration is:

	Position			Portion of Total Faculty Time on Administration
	Chairmen	Senior Scholars	Junior Scholars	
Weight:	.067	.439	.494	
Discipline				
Electrical Engineering	.038	.097	.069	.204
Mechanical Engineering	.037	.114	.059	.210
Civil Engineering	.031	.101	.049	.181

Expressing these data as percentages of administrative time only gives the following:

Discipline	Chairmen	Senior Scholars	Junior Scholars	Total
Electrical Engineering	19%	48%	34%	100%
Mechanical Engineering	18	54	28	100
Civil Engineering	17	56	27	100

These data are more comprehensible if it is noted that a two-hour meeting of a faculty of 15 would utilize 30 man-hours of administrative time, only 1/15th of which would be contributed by the chairman. Also, the bulk of advising students on their programs, which is administrative time, although consultations on courses is teaching time, is obtained from faculty.

Some Characteristics of Academic Administration

While the ECPD accreditation statement alludes to adequacy of administration without being specific, a pattern of administrative support can be generated from typical patterns. There is much similarity in the approach which will be used and that used to estimate minimum faculty. As was done for faculty, the minimum administrative team will be calculated for a very small college, and the numbers increased as necessary as the size of the student body increases.

As with faculty, there are skill barriers which limit the transferability of administrators among tasks. Administrators can be classified into three types:

- academic and discipline sensitive
- academic but not discipline sensitive
- nonacademic.

A departmental chairmanship is academic and discipline sensitive since he must be competent in one of the disciplines in his department. I interpret this restraint broadly, so that if the total engineering faculty in a small school combines electrical, mechanical, etc. engineers, the chairman can be drawn from any one of the fields. The restraint does not mean that there must be a separate chairman for each of several disciplines which are staffed by a faculty as small as three, but a single chairman can function for a small multidisciplinary department so long as the disciplines are strongly related.

Examples of academic but not discipline-sensitive positions are such functions as presidency, dean of students, admissions officer, etc. Nonacademic positions--for which academics are considered unsuitable--are positions of treasurer, in procurement, security, facility maintenance, and similar "business" functions of the college.

Within the general categories there is considerable flexibility of assignment. It is traditional that first and second-line academic administrators are drawn from teaching faculties, and continue to teach as well as administrate. The relative proportions of administration and teaching vary enormously, according to the administrative load.

The Cartter report gives a picture of the tradeoff between course load and the chairmanship. Following is the percent of workload decrease between senior scholars and chairmen, by discipline, and the percent increase in administrative duties:

Discipline	Reduction in Teaching Time	Reduction in Research Time	Increase in Administrative Time
	(Portion of 100% of all time)		
Electrical Engineering	28%	8%	35%
Mechanical Engineering	22	10	29
Civil Engineering	9	11	23
Mathematics	18	12	32
Chemistry	23	7	30
Physics	16	9	27
English	18	14	32
History	15	1	20
Economics	17	6	23
Philosophy	6	10	18
Average	17.2	8.8	26.9

Surprisingly, the combined reduction in teaching and research (of the averages) comes within one percentage point of the increase in administrative time. Chairmen generally reduce the combination of teaching and research by less than the increase in administrative time, which indicates that they put in extra hours so as to retain their teaching and research involvement despite the pressure of administrative duties.

An Administrative Workload Formula

How much time is needed for the first-line academic administrative function is taken to depend on the number of faculty, the number of students majoring in his subject and the number taking service courses in his department. This can be expressed as a formula:

$$T(c) = aF + bM + cS$$

where $T(c)$ is first-line administrative time in academic man-years; F is the number of faculty; M the number of majoring students and S the number of students taking service courses. The coefficients a, b, c can be based on a standard case. For example, a full-time chairmanship is common with a faculty of 25 and a student-faculty ratio of 15:1, or about 375 enrollments in courses in the department. In a typical discipline, about one-third of course enrollments are by departmental majors, who take an average of two courses in that major. Translating these registrations to student majors and nonmajors is as follows:

	Majors	Nonmajors	Totals
Course Enrollments	33 1/3%	66 2/3%	100%
# Courses in Department	2	1	
# Students Involved	16 2/3	66 2/3	83 1/3
% of Total Students	20%	80%	100%

Applying these percentages to 375 students, some values of the parameters of a, b, and c must be chosen such that

$$1 = 25a + 75b + 300c$$

If we assume that faculty normally take 50% of a chairman's time, majoring students 30% and nonmajoring students 20%, consistent parameters would be the following:

$$T(c) = .02F + .004M + .00067S$$

This formula can be used to estimate the workload of first-line administration for a minimal electrical engineering program. Suppose three 3-man engineering disciplines were combined in one department to make a nine-man engineering department, there were 200 majoring students--the result of an entering class of 50 a year--and no service course students. Then

$$T(c) = .02(9) + .004(200) = .98$$

and the chairmanship would be nearly a full-time job, which according to California data amounts to 60 hours a week during the academic year. But if mathematics, physics and chemistry were combined in one department (again, three 3-man disciplines) with 200 service students

$$T(c) = .02(9) + .00067(200) = .314$$

and the chairmanship could be performed in 19 hours a week. But Cartter shows that a senior faculty member spends about 20% of his time in administration, or 12 hours a week, so the chairmanship would take an additional seven hours; this could be obtained by reducing the teaching load according to the formula previously developed. If social science, English and history were combined into one department with a faculty of 12, since all students would be nonmajors, the value of T(c) would be .374 which would require a slightly greater relief.

In short, an additional administrator would be required for the engineering chairmanship even with entering classes of 50 students per year, if the chairmanship function is in-divisible, as it should be in proper administration. Other chairmenships could be filled from the surplus academic manpower.

Estimation with the Formula

Using the formula given above, first-echelon administrative workload has been calculated for a college offering solely an electrical engineering major, as shown in Table III-8. Since workload is expressed in academic year equivalents, the requirement can be compared directly with slack in academic manpower which is available for academic administration. The much larger administrative needs in engineering result from the larger faculties and because the formula postulates that majoring students need more administrator time than nonmajors.

There may be some limit to the extent to which first-line administrative functions can be spread around among a large number of persons. If so, it will not be possible to meet needs by combining a few spare hours each from a large number of faculty, and total faculty manpower may have to be increased to allow for concentration of administration in few hands. The administrative need under consideration is that done by chairmen and their staffs as opposed to the type normally delegated to faculty, such as committee work and advising students.

Since it is customary for administrative duties to be widely dispersed among the faculty, such a dispersal is at least feasible. Let us say that at least one-fifth of adminis-

TABLE III-8

FACTORS IN THE ADMINISTRATIVE WORKLOAD IN ACADEMIC YEAR EQUIVALENTS FOR A COLLEGE OFFERING ONLY A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, ORGANIZED INTO THREE DEPARTMENTS, 200 to 3200 STUDENTS

Department	Number of Students					
	200	400	600	800	1600	3200
Engineering						
Faculty	9	10	12	14	23	46
Majors	200	400	600	800	1600	3200
Nonmajors	0	0	0	0	0	0
Workload*	1.0	1.8	2.6	3.5	7.0	13.7
Sciences						
Faculty	9	9	9	10	17	33
Majors	0	0	0	0	0	0
Nonmajors	200	400	600	800	1600	3200
Workload*	0.3	0.4	0.6	0.7	1.4	2.8
General Education						
Faculty	12	12	12	12	13	26
Majors	0	0	0	0	0	0
Nonmajors	200	400	600	800	1600	3200
Workload*	0.4	0.5	0.6	0.8	1.3	2.7
Total Workload	1.7	2.7	3.8	5.0	9.7	19.2
Minimum Number of Persons Performing First-Line Academic Administration	3	4	5	6	11	20
Number of Persons Performing Higher-Echelon Academic Administration	2	2	2	2	2	3
Total Academic Administrators	5	6	7	8	13	23

*Workload of first-line administrators (chairmen, vice chairmen, and assistants) trative time must be concentrated in the chairman and his assistants, and that if there is no faculty member who has one-fifth of his teaching time as slack, then someone must be relieved of some teaching in order to perform the chairmanship. At the point where administrative time reaches five man years, there must be a full-time chairman with no teaching duties at all (or perhaps one course so as to keep his hand in). If the slack available from the remaining faculty is insufficient to make up the remaining four-fifths, some additional faculty must be relieved of teaching to perform administrative functions, possibly resulting in an increase in total faculty requirements.

It will be noted that--especially in the Engineering Department--the number of faculty and administrators becomes large enough with more than 800 so that it would be possible to divide the departments into a number of smaller departments. This would not increase the workload equivalent in first-echelon administration, though it might affect the minimum number of persons. This minimum, third line up from the bottom, is obtained by rounding the number in each discipline up to the next integer. It has not taken into account the number of persons from whom slack time must be put together, as has been done under the heading of each department (since slack in one department is not transferable to another).

Higher Academic Administration

Line administration is organized into a number of levels with a president at the top and the departmental chairmen at the bottom. The number of intermediate levels depends on the "span of control" which runs from six to ten in typical practice. At various levels, it may be supplemented by functional staff. The span of control and the size of functional staff are very much related to philosophies of administration, the kinds of problems and complexities of tasks faced by administrators--and what can be afforded. A round number might be that the total number of higher-echelon managers would be one-seventh the number of first-echelon managers.

However, for the accredited college there must be a limit to the extent to which dissimilar functions can be combined effectively. Separate higher-echelon management is considered to be required for the following functional groups:

I. Presidency

II. Academic Personnel
Student Administration

III. Financial Administration
    Treasurer
    Comptroller
    Budget Officer
    Payroll

IV. Facilities Management
    Nonacademic Personnel
    Procurement
    Maintenance
    Real Estate Management
    Parking

In short, a minimum of two higher-echelon academic managers and two nonacademic managers would seem to be required for even the smallest college. The two academic administrators would be sufficient (at the seven to one ratio) so long as there were no more than 14 first-line academic administrators, but with more, the number of higher-echelon managers would have to be increased.

The number of higher-echelon academic administrators and the total number of academic administrators are the last two rows, and are based on the rule of one higher-echelon administrator for each seven first-line administrators, but not less than two--president and a combined administrator of academic and student affairs on the academic side. If these numbers seem low, consider that they are based only on the academic function of the university, and that to the extent that residence, housekeeping, athletics, recreation, and some nondepartmental university functions are excluded the numbers are low.

IV. THE UTILIZATION OF FACULTY SLACK TIME

Summary

To recapitulate the philosophy underlying the calculation of faculty slack teaching time, it is considered to be zero for an individual faculty member when he makes four preparations and teaches six "normal" courses per year and has a normal load of administrative, student advising, and research duties. The minimum teaching loads and faculty have been calculated for student bodies ranging from 200 to 3200 and for a standard curriculum, making course assignments which minimize the number of preparations. This approach makes it possible to identify the maximum amount of slack.

Since the minimum faculty is determined by constraints, using this slack time does not increase the required number of faculty. However, it can be employed to perform some functions such as conducting recitation sections and academic administration for which personnel would otherwise have to be hired. To identify the cost of the least expensive accredited academic program leading to a BS in electrical engineering, these uses must have priority over other uses that might--at additional cost--improve the academic offering above that minimum quality.

Any remaining slack could be used to increase the number of optional courses, reduce class sizes, increase the research performance of faculty, or possibly in other ways (these options will be the ones explored). If some such slack actually exists, it is possible that a program somewhat better than the barest accredited program can be implemented at no increase in cost. Obviously any administrator will, within a cost constraint, seek to supply the best possible program which can be obtained without increasing faculty by allocating slack until it is fully utilized. Class-meeting capacity, preparation capacity, recitation section and administrative time are functions which take priority, as otherwise costly resources must be employed for functions that faculty could have performed at zero cost.

Table IV-1 summarizes the utilization of faculty manpower as a function of the size of the student body. Basically, the number of faculty is determined by the constraints already described, from the minimum teaching requirements expressed as class meetings (e.g., lecture sections) and preparations. There are also requirements for recitation quiz sections and laboratory sections, and faculty can be used for the former; where they do not have available class-meeting capacity, teaching assistants must be hired, and technicians must be hired as laboratory assistants. As is shown under the heading, "utilization of faculty teaching time," most time is utilized for course work, and an irregular but fairly constant amount of faculty time is available for meeting recitation sections as well as lecture classes.

TABLE IV-1

SUMMARIZATION OF UTILIZATION OF FACULTY TEACHING TIME AND ACADEMIC PERSONNEL REQUIREMENTS

Characteristic	Number of Students					
	200	400	600	800	1600	3200
Capacity of Minimum Faculty						
Number	32	33	35	38	57	111
Class Meetings	192	198	210	228	342	666
Preparations	128	132	140	152	228	444
Normal Class-Related Hours Per Week	800	825	875	950	1425	2775
Minimum Teaching Requirements						
Subjects in Curriculum	40	40	40	40	40	40
Lecture Sections	40	80	120	160	320	640
Preparations	40	40	40	47	80	127
Recitation/Quiz Sections	36	72	108	144	288	576
Laboratory Sessions	26	52	78	104	208	416
Supportive Academic Personnel Requirements						
Teaching Assistants (full-time)	0	0	4	11	46	92
Laboratory Assistants	5	7	10	12	23	44
Utilization of Faculty Teaching Time (hrs. per week)						
In Class, Preparation, Supervision of TA's, etc.	396	455	526	678	1214	2048
Recitations Met by Faculty, Preparations, etc.	216	348	324	372	180	252
Total Teaching Utilization	612	803	850	1050	1394	2300
Slack Teaching Time	188	22	25	(100)	31	475
(expressed in academic man years) (60-hour week)	3.1	0.4	0.4	(1.7)	0.5	7.9
Academic Administrative Requirements*						
First-Echelon Academic Administration, man years	1.7	2.7	3.8	5.0	9.7	19.2
Higher-Echelon Academic Administration, man years	2.0	2.0	2.0	2.0	2.0	3.0
Total, academic man years	3.7	4.7	5.8	7.0	11.7	22.2
Provided from Slack Teaching Time (man years)	1.7	0.4	0.4	0.0	0.5	7.9
Provided by Additional Academic Personnel (man years)	2.0	4.3	5.4	9.7	11.2	14.3
Remaining Slack Teaching Time (man years)	1.4	0.0	0.0	0.0	0.0	0.0

*Refers to workload beyond that normally borne by senior faculty, such as the additional load borne by departmental chairmen, deans, etc.

Expressing faculty slack in man years, it can be seen that for the very small and the very large enrollments there is a considerable amount of faculty slack teaching time which can be utilized for first-line academic administration. However, the amount is never sufficient to meet the needs fully, except for the 200-student enrollment--and if this could have been used for higher-echelon academic administration, there would never be any.

Indeed, it would be necessary to increase the number of academic personnel somewhat in order that the administrative workload could be adequately handled, except for the 200-student enrollment. Table IV-2 shows the total teaching manpower requirements, identifying minimum faculty and the additional faculty which would be necessary in order that administrative needs could be met. Of course, with the additional faculty on hand, it would be possible to shift course allocations around. The new minimum, based on teaching and administrative needs, would permit a whole new set of faculty assignment calculations, with more faculty members being assigned less than the AAUP 4-6 standard and thereby releasing faculty time for administrative duties. A full consideration of the implications of administrative requirements would probably alter these numbers somewhat, as there is much more flexibility in administrative workload calculations than in a system of firm constraints, and no attempt has been made to parcel out types

TABLE IV-2

SUMMARY ON ACADEMIC, TEACHING AND ADMINISTRATIVE PERSONNEL

	Number of Students					
	200	400	600	800	1600	3200
Minimum Faculty	32	33	35	38	57	111
Additional Faculty for First-Line Academic Administration (rounded up)	0	3	4	7	10	12
Higher-Echelon Academic Administrators	2	2	2	2	2	3
Teaching Assistants - Full-Time Equivalent	0	0	4	11	46	92
Total Academic Personnel	34	38	45	58	115	218
Laboratory Assistants	5	7	10	12	23	44
Total Teaching Personnel	39	45	55	70	138	262

of administrative activities or structure academic administration in detail; also, the disciplinary constraint is essentially ignored in calculating administrative needs for the college as a whole.

In certain cases, the combination of preparations and students generated a teaching workload that exceeded the norm, even though the AAUP 4-6 constraints were met. This was true of the electrical engineering departments with enrollments of 200 to 800. The overload did not arise from violation of the AAUP 4-6 standard, but because of the involvement with students directly, plus the need to supervise laboratory assistants, combined, of course, with the number of students. Under these circumstances some reduction in the normal administrative load and other nonteaching activities is justified; on the assumption that the relieved duties must be performed then by someone else, sufficient additional administrative manpower was added for that purpose.

APPENDIX

ASSUMPTIONS UNDERLYING CERTAIN CALCULATIONS

In calculating the faculty workload with teaching assistants and laboratory assistants, it has been assumed that the workload effect on a supervising faculty member of a recitation, quiz or laboratory section is equivalent, but that no supervisory workloads are generated when the faculty member handles a quiz section associated with a course in which he lectures. Thus, the workload is generated according to the number of sections that do actually have TA's and of course all laboratories.

It will be recalled that courses taught with and without TA's were considered to generate different time demands per student on the faculty member. The time demand with TA's was considerably less, on the assumption that the TA's acted as buffers between the faculty member and the students, correcting exams and the like. This coefficient is considered to be the appropriate one whether or not the faculty member doubles as a TA. His workload generated by students as a course leader in a course with TA's is independent of whether he is also serving as one of the TA's. However, if he so serves, the number of TA's would be reduced, and the time requirement for consulting with TA's also, as it reflects only the actual number of TA's. Where there is both lab and recitation, it counts as two supervisions.

Using the formula, the workload has been calculated on a per-department basis, as a function of the number of subjects taught with and without TA assistants, taking students taught directly and indirectly (through TA's) into account as well as the number of TA's.

Students in labs are dealt with directly, and the .04 coefficient applies, since technicians as lab assistants cannot relieve instructors of this load. That is, courses with labs are distinguished from recitation sections by generating the student-related workload of a directly taught course, and a TA-related workload due to supervision of the lab and the laboratory assistant.

Where a faculty member is used to handle recitation sections, the workload generated can be calculated by the formula already used, on the assumption that there is no subject preparation (as he has already prepared lectures and instructions for TA's), that time utilization per three recitation sections is the same as for a directly met class (e.g., a coefficient of three), and the time demand of the students is the coefficient for dealing with them directly (e.g., .04). If a faculty member meets three sections for a total of 75 students, then the total time demand is:

$$H(T) = 3 + .04 \times 75 = 6 \text{ hours per week}$$

of which three hours is spent in the classroom conducting three recitation sections. This effort by faculty is allocatable to faculty teaching time. In the table, the utilization of faculty teaching time on an hourly basis is based on the six hour figure multiplied by the number of recitation sections that faculty conduct directly.

One problem is determining the number of preparations which are and are not assisted, as a function of the number of students. For example, there are five courses in electrical engineering which are assisted by laboratory assistants. Where there is a single 50-student class for each of the 12 electrical engineering subjects, obviously there are seven unassisted and five assisted classes. However, when the student body increases to 800, there are 17 preparations in electrical engineering, and it is necessary to determine what proportion is of assisted classes, since assistance makes a difference in the estimation of preparation time. In the previous calculation of minimum faculty, all courses were anonymous, as it was assumed that there was interchangeability of faculty within a discipline.

Since the thrust/of this investigation is to provide an accredited curriculum at least cost, courses for which--in the least faculty configuration--several faculty must make a preparation should be chosen from those for which TA's are not required, since their preparation time is somewhat less than for courses with TA's.

Following this principle, the number of preparations in assisted and nonassisted classes has been calculated. The principle of calculation is to count the number of assisted courses. If it is no greater than the number for which only a single preparation is necessary, no increase in the number of preparations in assisted courses is needed; multiple preparations can be concentrated in unassisted courses. Assisted courses should be concentrated among those with the least number of preparations.

V. THE EFFECT OF PROGRAM ENHANCEMENT ON FACULTY REQUIREMENTS

Introduction

The barebones or baseline program has been used for developing the minimum faculty requirements for classroom instruction and academic administration of a program that meets accreditation with the minimum possible faculty, given certain constraints. It is probably not a program that any college would be willing to offer, or which could even attract as many students as the postulated enrollments.

The faculty requirements of programs with more desirable characteristics can be calculated by changing the constraints and redetermining the minimum faculty as a function of scale. In the following, one constraint at a time will be changed, in order to isolate its effects. It is possible to relax several constraints concurrently, though in doing so the individual effect of each would be somewhat obscured.

Many, if not all, enhancements of the baseline program would increase faculty numbers and hence the faculty wage bill. In accepting additional costs, the college administration is faced with two analytical tasks. One is conducting either intuitive or formal cost-benefit analyses of alternative ways in which it could improve the program. The second is determining what total costs it is able to meet, as a result of enhancing the program above the baseline, by all possible ways.

In such analyses, the cost of specific program steps can be calculated by the techniques already used in this paper. However, the educational value of such enhancements as more optional subjects, smaller classes, etc. cannot be measured easily, and the selection is ultimately a value judgment made by members of the college community, as they are able to make themselves effective within the structure of college governance.

A principal purpose in articulating the baseline program was to provide a foundation on which such cost-benefit comparisons could be based. It is truly a base if there is no possible accredited program beneath it. This may not be absolutely so--for example, with respect to class size--but it is probably very close. Taking the baseline as a starting point, an increment in number of subjects can be compared with the associated increment of cost. Then, the increment of cost with more subjects or with reduction in class size can be compared with the increment of cost. If the analysis is arranged so that the cost increments are identical, costs are constant at a new, higher level, and the academic desirability of the options increment and the class size increment can be compared directly, setting cost considerations aside for the moment. This is a basic technique of cost-effectiveness analysis.

Increasing the Number of Subjects Offered

Increasing the number of subjects in the curriculum beyond the baseline minimum of 40 is certainly one of the improvements that would be attractive to any faculty. Thus, a functional relationship between number of subjects beyond 40 and the minimum faculty is of interest.

In the model used here, it is sometimes possible to increase the number of optional subjects at no increase in faculty at all. If there is any benefit at all in more options, the benefit-cost ratio under these conditions is very high--so much so that even engineering education at the very minimum possible cost need not present a program limited to 40 subjects. The question is, how much may the curriculum be broadened above the baseline 40 without increasing faculty. It depends on the size of the school.

Increasing options without increasing costs is possible wherever several faculty members prepare the same course. They can instead prepare different courses with no increase in preparations or class meetings, provided that the enrollment in the two courses is allocated so that no additional faculty would be needed. Under the baseline assumptions, this would mean that each of the options would need to enroll 50 students. That is, if one of the options only enrolled 30, an additional 20 would need to enroll elsewhere, and if the 50-student limit were observed, it would be necessary to add a section and thereby increase the teaching load. As this would reduce the faculty time for administrative duties, it would increase cost.

For example, under the minimum preparation guidelines of the baseline program for an enrollment of 800 in electrical engineering, three courses would be prepared by two different faculty members, and one would be prepared by three. The five duplicate preparations could be allocated to additional optional subjects, without increasing faculty requirements. It will be seen from Table V-1 that such possibilities exist only for colleges with fairly substantial enrollments, as with enrollments of 600 or less, there are no duplicate preparations.

Of course, colleges can increase the number of options beyond this point if they are worth the cost. For each additional faculty member four additional subjects can be offered. Thus, Figure V-1 shows a slope of courses versus faculty which relates faculty to options in the ratio 1:4. The origin point of the curve for an enrollment of 200 is 40 courses and 32 teaching faculty (leaving out administrators). Below this point the curve does not exist since no program is possible. The slope is 1:4 regardless of enrollment, but only with enrollments of 800 or more can course offerings ever be increased without increasing faculty. For the very large college a considerable breadth of options can be offered without any additional cost, but for the smallest three, any increase at all in the number of courses affects faculty requirements.

One hoped-for circumstance, that might have permitted a further increase in options without costs, did not materialize

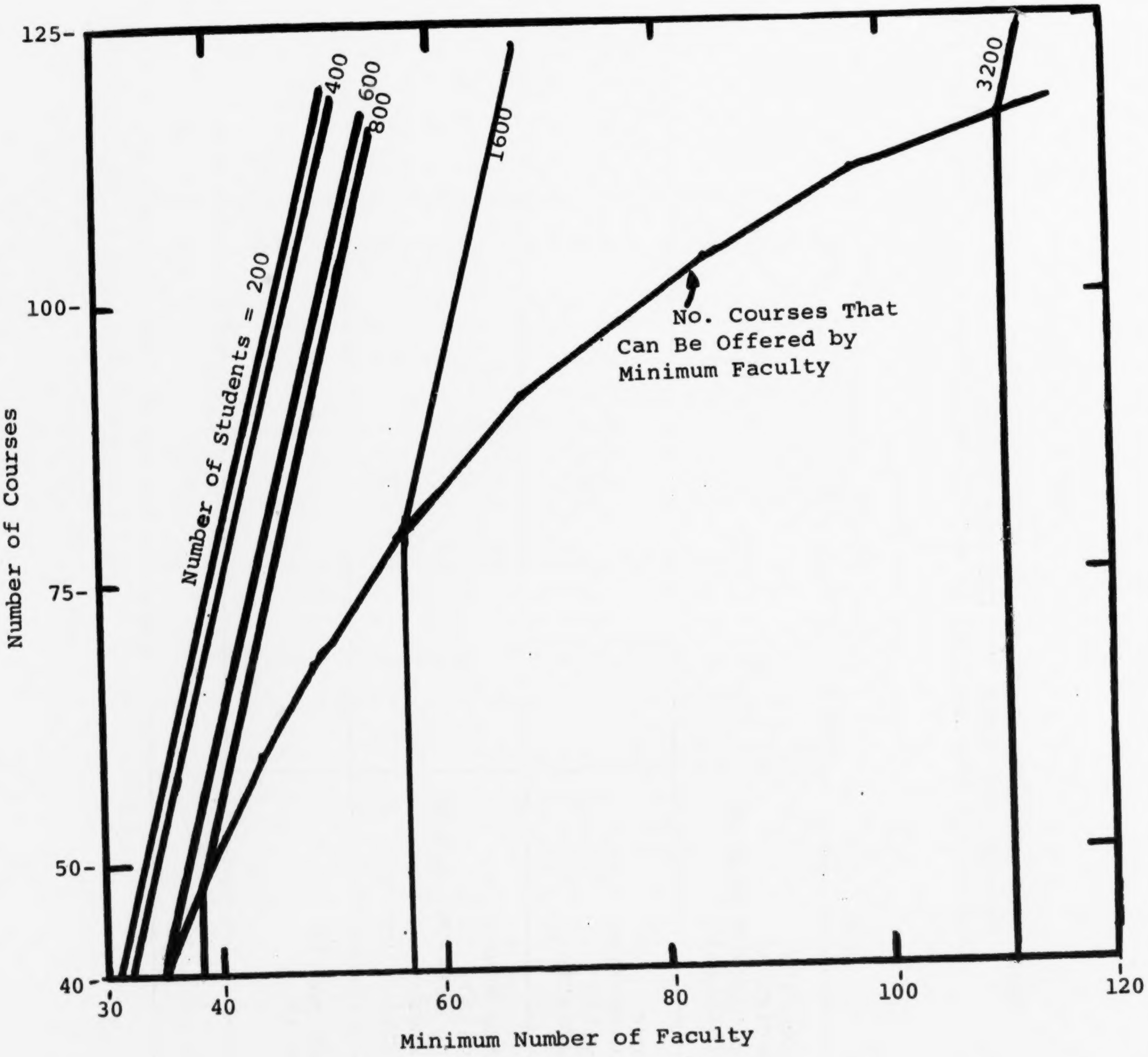
TABLE V-1

NUMBER OF SUBJECTS THAT CAN BE OFFERED WITHOUT INCREASING COURSE PREPARATIONS OR MEETINGS ABOVE THE MINIMUM REQUIRED IN A 40-SUBJECT CURRICULUM, ELECTRICAL ENGINEERING BS MAJOR; ENROLLMENTS OF 200 to 3200 STUDENTS

	Number = 40-Subject Curriculum	Number of Students					
		200	400	600	800	1600	3200
Engineering							
Electrical	12	12	12	12	17	24	28
Engineering Science	3	3	3	3	3	6	10
Mechanical	2	2	2	2	2	4	6
Sciences							
Mathematics	6	6	6	6	8	12	20
Physics	4	4	4	4	5	8	13
Chemistry	2	2	2	2	2	4	6
General Education							
English	3	3	3	3	3	6	10
Fine Arts/Philosophy	2	2	2	2	2	4	6
History	2	2	2	2	2	4	6
Social Science	2	2	2	2	2	4	6
Health and PE							
Health	1	1	1	1	1	2	3
PE	1	1	1	1	1	2	3
TOTAL	40	40	40	40	48	80	117

FIGURE V-1

MINIMUM FACULTY NEEDED AS A FUNCTION OF COURSES IN CURRICULUM, FOR ENGINEERING COLLEGES WITH PROGRAMS LEADING TO BS IN ELECTRICAL ENGINEERING, 200 to 3200 STUDENTS



from the calculations, but might be a factor in some other model. It was thought possible that after teaching and administrative uses of faculty had been met some slack time might be left to enrich the program without increasing faculty. But only in the 200-student program was there any remaining slack, and the total amount was small--allowing only five or six optional courses, with none in electrical engineering. The desirability of a substantial number of options may be low in engineering. This is suggested by the limited numbers of options in most accredited programs; however, there is a trend toward allowing students more flexibility in course selection, indicating a desire for a larger number of options than is typical at the present.

For example, the University of Maryland electrical engineering majors are allowed only 15 hours of technical electives, three of which must be, and 12 of which can be, in electrical engineering. Three to 12 must be taken in other engineering and science to make up a minimum total of 15. Seventeen three-semester hour undergraduate courses are available in electrical engineering, plus some laboratory courses, and supervised special study as options. The possibilities in other engineering and sciences are considerable.

Options in general education must be allocated in a rigid pattern among broad disciplinary areas, such as history, social sciences, etc. At Maryland, four courses in English are suggested by the catalog where three are required; 27 are suggested in fine arts or philosophy where one is required; 16 are suggested in history where two are required; 8 are suggested in social science where two are required. Since lack of previous exposure to these disciplines means that optional courses must be at the introductory level, there is some practical limit to how many in any discipline can be consistent with sound pedagogy.

An Alternative Class Size Constraint

Small class sizes are generally thought to add something to the educational experience, especially if the teaching skill of the faculty is not downgraded as class size is reduced. Often it is; large classes are often taught by skilled senior professors and small sections by half-qualified teaching assistants; however, at this point faculty quality is not under consideration but only faculty numbers.

One common policy is to offer lower-division subjects, primarily introductory courses, in very large classes and to hold down enrollments in upper-division courses. In order to determine the effect of such a policy, the assumption was made that class sizes could be as large as 100 in lower-division courses, general education and health or physical education courses. Upper-division classes would be limited to 25. The effects of the assumptions for the 40-subject electrical engineering curriculum are presented in Table V-2. Since most of the electrical engineering courses are upper division, it is in this discipline that most of the small classes are to be found. This new policy does not affect the numbers of recitation or laboratory sessions, if they continue to be held to a 25-student limit. Recitation sessions would be associated with the larger classes and are relatively infrequent in upper-division courses. The total number is not changed.

The table shows faculty requirements as a function of size, as worked out with faculty assignment sheets. In some instances--with a 200-student enrollment for example--there are not sufficient students to fill up a class of 100, so that enrollment is actually 50, and the quality of the educational experience, to the extent that it is affected by class size, cannot be held constant.

Comparing the minimum faculty under the 100-25 constraint with the uniform 50-student constraint, it will be seen that it imposes a definite though modest increase on total faculty requirements. The concentration of the smaller classes in electrical engineering subjects means that the distribution among disciplines of the faculty is altered. For example, in the 800-student colleges which graduate 200 BSEE's per year, the faculty in electrical engineering must be increased from eight to 15, and every other discipline would be able to accomplish its teaching tasks with a three-man faculty. In the

TABLE V-2

MINIMUM FACULTIES FOR COLLEGES OFFERING ONLY A 40-SUBJECT ELECTRICAL ENGINEERING BS MAJOR, AAUP FACULTY LOAD, CLASS SIZE LIMITED TO 100 IN LOWER DIVISION AND 25 IN UPPER DIVISION SUBJECTS, SEMESTER PLAN EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS

	# of Courses			Number of Students					
	Total	100	25	200	400	600	800	1600	3200
Engineering									
Electrical	12	1	11	4	8	12	15	30	60
Engineering Science	3	3	0	3	3	3	3	3	4
Mechanical	2	0	2	3	3	3	3	6	11
Sciences									
Mathematics	6	5	1	3	3	3	3	6	12
Physics	4	3	1	3	3	3	3	5	10
Chemistry	2	2	0	3	3	3	3	3	3
General Education									
English	3	3	0	3	3	3	3	3	4
Fine Arts/Philosophy	2	2	0	3	3	3	3	3	3
History	2	2	0	3	3	3	3	3	3
Social Science	2	2	0	3	3	3	3	3	3
Health and PE									
Health	1	1	0	1	1	1	1	2	3
PE	1	1	0	1	1	1	1	2	3
TOTAL	40	25	15	33	37	41	44	69	119
TOTAL for Uniform 50-Student Class Size Limit	(See page III-4)			32	33	35	38	57	111
Additional Faculty Required for 100-25 Plan				1	4	6	6	12	8

3200-student college, only electrical and mechanical engineering would have increased faculties, and all of the others are reduced.

Excess preparation capacity is effected also. Total preparations in electrical engineering are as follows:

	Number of Students					
	200	400	600	800	1600	3200
100-25 plan	4	17	36	37	82	168
Uniform 50 plan	0	4	12	15	40	88

Thus, there would be considerable offset to the larger faculty requirements by increasing the extent to which faculty would be available for administration, though of course administrative needs of the larger faculty would be slightly higher. For example, 3200 student-majors enrollment and 60 faculty has a first-line administrative requirement in electrical engineering of 14 academic man-years. The 4000 enrollments in laboratory courses would have to be handled by 27 supervised full-time laboratory assistants. As the 9600-student total of course enrollments in electrical engineering would all be met directly, the formula estimate of teaching hours would be 1931 hours per week compared to the normal load for a faculty of 60 of 1500 hours per week.

Alternative Faculty Assignment Policies

Of the course assignments to faculty under the minimum faculty plan, assigning one man to teach all sections of a course up to six deviates most from usual practice and would probably be found objectionable. Further, no distinction was made between semesters in the model. If courses are offered only once a year, for a professor to meet six classes in the same subject would imply fulfilling his entire teaching commitment in just one semester, since that would be the AAUP yearly load limit. Thus, it serves jointly the purpose of realism and exploring alternative policies to postulate as an additional constraint that three classes for a faculty member in the same subject be an additional constraint. Since the optimum policy is often six, this constraint could have increased faculty numbers.

The effect of the additional constraint was calculated for electrical engineering where lower-division courses were limited to 100 and upper-division courses to 25 students. This produced no increase in faculty requirements. However, it did reduce the slack available for administrative duties by increasing the minimum number of preparations, as follows:

	Number of Students					
	200	400	600	800	1600	3200
Up to 6 classes per Preparation	12	15	12	23	38	72
No more than three Classes per Preparation	12	21	23	34	68	129

The vast amount of slack preparations available, which was not exhausted by the additional demands of the three classes per preparation limit, was the reason that no increase in faculty was necessary. Quite possibly no additional faculty would have been required with a two classes per preparation limit, though under the AAUP six and four rule slack should be exhausted. Of course, a policy of no duplication of classes based on the same preparation would effectively impose a four-section limitation on faculty.

There is a common tendency for academic departments to use up excess teaching capacity by offering optional courses, even when this subtracts from the amount of slack time that might otherwise be available for administrative duties. The considerable number of excess preparations that are available above the minimum allow considerable scope for this. However, under the minimum faculty plan there is rarely much excess class meeting capacity, and preparation capacity is principally available for increasing the number of subjects without increasing the number of course offerings, or by avoiding repetition in the classroom based on the same preparation.

Perhaps faculties feel that teaching and course preparation are their principal duties and that use of slack time for administration must always take a back seat to broadening and enriching the educational experience. This view, carried beyond a certain point, means the hiring of additional personnel for administration as faculty are not available, and broadening the curriculum in these circumstances is not costless to the college. No one would argue against enrichment even when it costs, but the scale at which cost increases first appear is that at which administrators must be added, not faculty.

Other Faculty Workload Policies

Any additional constraint on the employment of faculty must be analyzed to see if it increases the faculty workload and possibly the minimum faculty. Relaxation of constraints may reduce the minimum faculty. Obviously relaxing the AAUP standard workload with respect to class meetings, changing a nine to a 12 semester hour load would have a direct effect. The preparations standard was already in operation so that its relaxation would have meaning only if a policy of less than two classes per preparation were followed. If it were, then relaxing the preparations constraint would make it possible for very small colleges to increase the number of subjects without increasing the number of faculty. As was shown in Figure V-1, only with enrollments of 800 or more was any increase in the number of optional subjects possible without adding faculty. Even larger colleges might increase further the number of options, if it were possible without cost and within teaching load standards.

Policies Related to Contingencies and Staffing Emergencies

In many of the analyses reported above the minimum faculty was just sufficient to meet teaching requirements. The turnover rate among faculties, as well as sudden losses due to illness, etc., makes some ability to take care of emergencies almost essential. This can be achieved by having personnel who are assigned to postponable though important duties--e.g., research and some administration. Indeed, most faculties are able to operate successfully when understaffed because curricula, course sizes and workload are not actually as inflexible as has been assumed for model development purposes.

An additional consideration is continuity in the content of a course offering difficult to insure when a course is presented by only one faculty member. This is an argument for scheduling important courses for at least two faculty members. Optional subjects, which are often the specialty of some individual, can be dropped from the curriculum with his unavailability or reassignment. With a three classes per preparation policy, except for the 200-student college, there were very few instances of courses prepared by only one faculty member. However, they were nearly the rule where classes went as high as six. In short, the three class limit has a contingency protection attribute as a desirable zero cost by-product (or the other way around, if you prefer).

The relationship between the amount of additional faculty retained for protection against contingencies and the amount of risk might well be explored further. Suppose that faculty members are found to leave on the average once in five years. A one-man department would have a complete break in continuity, on the average, once in five years but sometimes much oftener. Assuming that departures were random and independent (which is unlikely), the probability of complete discontinuity in a two-man group would be much lower, and in a three-man group much lower still.

The exact figures depend on the frequency distribution of departures. A study by Dunham, Wright and Chandler surveyed faculties and reported the probability of moving annually from one university to another as a function of age:

Under 30	.195
30 to 39	.061
40 to 49	.031
50 to 59	.024
60 and over	.012

These data understate losses by omitting retirement and losses to industry. By academic rank, the probability of moving runs from .137 for instructors to .012 for full professors. The leave rate by discipline for all ranks combined is:

Engineering	.015
Sciences	.040
Humanities	.079
Social Sciences	.103

It can be postulated that the emergency spare faculty is at least one full man beyond the minimum and one spare man for every five. This produces an excess of four preparations and six courses as a minimum. However, this does not assume idleness--the manpower is available for postponable administrative or other duties.

Excess teaching capacity can be utilized in optional courses which need not be offered when faculty must concentrate on essential courses and can otherwise be used to enrich the curriculum. In the faculty assignment process, the cost of such excess manpower can be taken into account by including "dummy courses" in the ratio equal to which is thought to be the necessary reserve. Calculating the minimum faculty proceeds as before.

Clearly the risk and cost is greater with smaller groups; the exact risk is highly problematical and not merely a function of the number of men but of the particular men. The lack of independence of departures is important.

Other Relaxations of Constraints

The above analyses have depended on the explicit specification of constraints, which have made it possible to calculate exact faculty numbers. The rigidity with which the constraints have been interpreted is undoubtedly very artificial. Flexibility is rife in academia; there is seldom an absolute class size limit, and in cases of necessity a few more students are always squeezed in. The AAUP statement on workload recognizes the flexibility of faculty work assignments. Obviously, when calculations strictly in terms of the constraints call for more than the faculty on hand, the additional work may be parcelled out. The amount of administrative work, student consulting and class preparation is not rigidly fixed, and with heavy assignments adjustments are made informally. Of course, these amount to changes in the quality of education

The idea that quality must be held absolutely constant, though useful in a model, does not recommend itself to a practical academic administrator who knows that the quality of instruction varies enormously from classroom to classroom and is barely under administrative control. Looking across the spectrum of teaching in his department, he would recognize that it would be reasonable to violate some constraints if there were offsetting considerations. The importance of this point is that flexibility may reduce the faculty requirements below the minimum calculated for the baseline program without sacrificing quality.

In addition to the formal constraints, several formulae have been used for calculating workload in hours. The parameters in formulae for calculating first-line administrative manpower affect faculty numbers very much as do constraints. If the parameters were changed, the estimated slack time would be affected on the one hand and the amount that would be needed for administrative purposes on the other.

The parameters values used were derived judgmentally from data, and if they are accurate, they represent average rather than best performance. In this sense, they deviate from the optimization principle. Thus, the formula for first-echelon administrative manpower expresses how much a department with average administrative staffing would devote to administration, if it had the specified number of faculty and students. Perhaps efficient performance of the administrative function would make effective administration possible with much less time.

One implicit assumption, virtually a constraint, is that there would be no change in instructional technology, but a given curriculum will continue to be taught by traditional methods. Teaching methods and the course of study might be examined in a broader study.

VI. FACULTY REQUIREMENTS IN A COLLEGE WITH THREE MAJOR AREAS

Introduction

No engineering colleges or engineering departments in universities offer only a single major. Sometimes many are offered, some being specialties within a general area, or interdisciplinary combining several types of engineering, or engineering with subject area knowledge. For example, computer science is mainly specialized electrical engineering, and agricultural engineering is mainly mechanical engineering oriented toward particular applications.

Typically, whatever the specialty, undergraduate students take the same science, general education and "core" engineering subjects, and this comprises most of their first two years of study. The last two years place more emphasis on their special subject area.

As a result, the minimum number of course offerings for three majors is not three times as large as for one. As was shown in Table II-2, a college can offer electrical, mechanical and civil engineering with a curriculum of 94 courses, while any one of these three alone would require 47 to 48 courses. Faculty requirements are affected in the same way.

What does it involve in terms of minimum faculty to offer a number of major areas instead of one? Consider the case of a college offering electrical, mechanical and civil engineering majors. Compared to the college offering only electrical--

and referring to the curricula of Table II-2--it must add faculty for only one additional discipline, civil engineering. The economics course required in the civil engineering program means that the social science option must be in that discipline to minimize faculty requirements.

The minimum faculty for this case has been worked out, as a function of size of student body on the assumption that students are equally divided among the three disciplines; faculty numbers may be affected by the proportions. A 50-student limit to class size has been used. Thus, with an enrollment of 200, or 50 students per class, the lower division, science and core engineering subjects would have precisely the same 50-student enrollment in the college with 200 students, regardless of the number of majors. In specialized courses in each of the three areas there will be only one-third of that, and courses taken by two of the three groups would have two-thirds of it.

For example, with an enrollment of 600, or 150 per class, some subjects would have 150 students, or three 50-student sections, while others would have a single section of 50; with a 200-student enrollment, some would have 50 and the others (approximately) 17. Table VI-1 shows the number of courses which would be taken by electrical, mechanical and civil engineering majors by discipline. Included are options allocated to disciplines which would permit students to complete their programs according to reasonable expectation of student interest. It

TABLE VI-1

NUMBERS OF COURSES AND SEMESTER HOURS* BY DISCIPLINE TAKEN BY MAJORS IN ELECTRICAL, MECHANICAL, AND CIVIL ENGINEERING, AND COMBINATIONS OF THESE THREE

Discipline	Electrical	Mechanical	Civil	ME & CE	All Three	Total	
						Courses	Semester Hours
Engineering							
Engineering Science+	2(3)	1(3)		1(3)	3(9)	7	18
Electrical**	18(47)	4(8)	1(3)			23	58
Mechanical	1(3)	19(54)	1(3)			21	60
Civil			18(51)			18	51
Science							
Mathematics	2(6)				4(16)	6	22
Physics	1(3)				3(12)	4	15
Chemistry					2(8)	2	8
General Education							
English					3(9)	3	9
Fine Arts/Philosophy					1(3)	1	3
History					2(6)	2	6
Social Science (Economics)			3(9)		2(6)	5	15
Health and Physical Education							
Health					1(2)	1	2
Physical Education					2(2)	2	2
TOTAL	24(62)	24(65)	23(66)	1(3)	23(73)	95	269

*Semester hours denoted in brackets, courses without.

**Includes 5 laboratory courses for electrical and 2 for mechanical engineering.

+Includes 1 laboratory course for electrical engineering.

is assumed that the optional course that would be needed as a nonelectrical engineering technical elective for electrical engineering majors would be offered in mathematics, that the social science offering taken by all is in economics and that the two nonengineering electives which are required of civil engineering majors are also in economics.

The table shows that 23 courses are taken by all students, including chemistry, general education, health and physical education courses. For these subjects, faculty requirements are unaffected by the number of areas in engineering and depend only on the total number of engineering students.

Faculty requirements in one engineering discipline are often only slightly affected by the presence of the others. For example, professors in civil engineering teach none of the students majoring in mechanical and electrical engineering, and professors in these two areas teach only one course each to civil engineering students. In a college with only a civil engineering program, the minimum faculty of three each in electrical and mechanical engineering would have made it very expensive to provide the civil engineering students with their required electrical and mechanical engineering courses. Where these disciplines have programs in their own right, the three-man minimum loses significance, and the cost is much less.

Table VI-2 shows the minimum faculty requirements for a three-major program as a function of the number of students, distributed by discipline. There is an element of noncomparability in class size that can be avoided only by comparing an electrical engineering program and three-area program for 600, 1200, 1800, etc. students. This has been done in order to permit a more meaningful comparison. The effect of offering majors in three fields is to increase faculty requirements in engineering rather considerably and to alter the distribution of faculty among disciplines. The comparison between a one-major program and a three-majors program could, of course, be repeated for mechanical or civil as well as electrical engineering.

Comparing this table with the following table shows that the effect on electrical engineering faculty is most striking. When only one-third of 3200 students major in electrical, it has a faculty of 16 out of a total engineering faculty of 68, but when all of the students major in electrical, its faculty more than doubles to 35, although the total engineering faculty drops to 52. The engineering science faculty is little affected. As only one course in mechanical is taken by electrical engineering majors, this faculty would drop from 21 to three if all students were electrical engineering majors, and the civil engineering faculty would drop out completely.

Regardless of college size, the net effect of offering three majors is an increase in faculty. In the smallest

TABLE VI-2

MINIMUM FACULTIES FOR COLLEGES OFFERING MAJORS IN ELECTRICAL, MECHANICAL AND CIVIL ENGINEERING, AAUP FACULTY LOAD, 50-STUDENT CLASS SIZE LIMIT, SEMESTER PLAN, EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS DIVIDED EQUALLY AMONG THE THREE MAJORS

	Number of Students							
Discipline	200	400	600	800	1200	1600	2400	3200
Engineering								
Engineering Science	3	3	3	4	5	7	10	13
Electrical*	4	4	4	6	6	8	11	16
Mechanical	6	6	6	7	7	11	14	21
Civil	5	5	5	6	6	9	12	18
SUBTOTAL	18	18	18	23	24	35	47	68
Science								
Mathematics	3	3	3	4	5	7	10	13
Physics	3	3	3	3	4	5	7	10
Chemistry	3	3	3	3	3	3	4	6
SUBTOTAL	9	9	9	10	12	15	21	29
General Education								
English	3	3	3	3	3	4	6	8
Fine Arts/Philosophy	3	3	3	3	3	3	3	3
History	3	3	3	3	3	3	4	6
Social Sciences (Economics)	3	3	3	3	3	5	6	9
SUBTOTAL	12	12	12	12	12	15	19	26
Health and Physical Education								
Health	1	1	1	1	1	2	2	3
Physical Education	1	1	1	2	2	3	4	6
SUBTOTAL	2	2	2	3	3	5	6	9
TOTAL	41	41	41	48	51	70	93	132

*faculty to teach 16 lecture courses, excluding 7 exclusively laboratory courses

TABLE VI-3

MINIMUM FACULTIES FOR COLLEGES OFFERING ONLY A MAJOR IN ELECTRICAL ENGINEERING, AAUP FACULTY LOAD, 50-STUDENT CLASS SIZE LIMIT, SEMESTER PLAN, EXCLUDING LABORATORIES AND SECTIONS, 200 to 3200 STUDENTS

Discipline	Number of Courses	Number of Students							
		200	400	600	800	1200	1600	2400	3200
Engineering									
Engineering Science	5	3	3	3	4	5	7	10	14
Electrical	13	4	5	7	9	13	18	26	35
Mechanical	1	3	3	3	3	3	3	3	3
SUBTOTAL	19	10	11	13	16	21	28	39	52
Science									
Mathematics	6	3	3	3	4	6	8	12	16
Physics	4	3	3	3	3	4	6	8	11
Chemistry	2	3	3	3	3	3	3	4	6
SUBTOTAL	12	9	9	9	10	13	17	24	33
General Education									
English	3	3	3	3	3	3	4	6	8
Fine Arts/Philosophy	1	3	3	3	3	3	3	3	3
History	2	3	3	3	3	3	3	4	6
Social Sciences	2	3	3	3	3	3	3	4	6
SUBTOTAL	8	12	12	12	12	12	13	17	23
Health and Physical Education									
Health	1	1	1	1	1	1	1	2	3
Physical Education	2	1	1	1	2	2	3	4	6
SUBTOTAL	3	2	2	2	3	3	4	6	9
TOTAL	42	33	34	36	41	49	62	86	117

colleges, an increase of eight is needed. Faculty requirements do not increase proportionately to the number of majors offered _provided_ that there are mutually supportive relationships between the various disciplines.

Calculating Faculty Requirements From Program Specifications

In the introductory chapter it was stated that a faculty requirement model could be used to identify the minimum faculty requirements for the program of an actual college. A hypothetical engineering college with different characteristics as follows has been chosen by way of illustration:

- majors in electrical, mechanical and civil engineering
- class sizes up to 100 in lower division courses but limited to 25 in upper division courses
- no more than three courses based on a single preparation
- all other constraints as before.

While not the program of a specific college, it is a reasonable approximation of what many offer and common distributions of students among majors. It can be accepted as an acceptable program, with the possible exception of the limited options and no graduate program; the additional faculty requirements will be explored subsequently. There is much that is attractive in combining several major areas in one engineering college; it avoids narrowness; it permits the college to meet the needs of a larger number of students; introductory courses in other major areas can serve as options for students without requiring additional faculty; students who are uncertain as to their talents and interests can switch majors when part way through their program without excessive inconvenience.

Table VI-4 gives minimum faculty requirements for the specified program. Comparing it with Table VI-2 it will be seen that faculty requirements in engineering have been increased for all enrollments above 400 students. However, in the sciences and general education, faculty requirements have been reduced, the reduction approximately offsetting the increase in engineering faculty, so that total faculty is changed only a little. As before, this results from larger lower division classes concentrated in the nonengineering subjects and the restriction of upper division courses to 25--much more heavily engineering. The constraint of no more than three courses per preparation did not increase minimum faculties in any case, though by increasing the number of preparations it reduced faculty slack time.

The fact that approximately the same size faculty is needed for a given number of engineering students, regardless of whether the across-the-board 50-student class size limit or the 100-25 limit is used, has implications for cost accounting practice. Class enrollments per faculty member differ widely under the two systems, since a fully occupied faculty member under the uniform 50 policy would pick up 300 class cards per year, or 50 for each of six sections, but under the 100-25 policy fully

TABLE VI-4

MINIMUM FACULTIES FOR COLLEGES OFFERING MAJORS IN ELECTRICAL, MECHANICAL AND CIVIL ENGINEERING, AAUP FACULTY LOAD SEMESTER PLAN EXCLUDING SECTIONS AND LABORATORIES WITH 200 to 3200 STUDENTS DISTRIBUTED 50% ELECTRICAL, 25% MECHANICAL AND 25% CIVIL; CLASS LIMIT 100 IN LOWER DIVISION AND 25 IN UPPER DIVISION COURSES

Discipline	Number of Subjects	Number of Students							
		200	400	600	800	1200	1600	2400	3200
Engineering									
Engineering Science	7	3	3	3	3	4	5	7	10
Electrical	16	4	5	8	10	14	19	28	37
Mechanical	21	6	6	7	7	11	14	21	28
Civil	13	4	4	4	4	6	8	12	16
SUBTOTAL	57	17	18	22	24	35	46	68	91
Sciences									
Mathematics	6	3	3	3	3	4	6	8	11
Physics	4	3	3	3	3	3	4	5	7
Chemistry	2	3	3	3	3	3	3	3	3
SUBTOTAL	12	9	9	9	9	10	13	16	21
General Education									
English	3	3	3	3	3	3	3	3	4
Fine Arts/Philosophy	1	3	3	3	3	3	3	3	3
History	2	3	3	3	3	3	3	3	3
Social Sciences (Economics)	3	3	3	3	3	3	3	3	4
SUBTOTAL	9	12	12	12	12	12	12	12	14
Health and Physical Education									
Health	1	1	1	1	1	1	1	1	2
Physical Education	2	1	1	1	1	1	1	1	2
SUBTOTAL	3	2	2	2	2	2	2	2	4
TOTAL	81	40	41	45	47	59	73	98	130

occupied faculty would pick up either 600, if they were teaching lower division courses, and 150, if they were teaching upper division courses. Since lower division courses are principally nonengineering and upper division courses predominantly engineering, it would appear in the latter case that the "productivity" of the engineering faculty, as measured by the number of class enrollments per faculty member, would be low. Yet there is no difference in total faculty cost per student under the two policies, and the choice can therefore be based on educational considerations. The accounting system that presumes to show engineering education is more expensive under the 100-25 policy is creating an illusion.

Increasing the Number of Optional Subjects

The relationship between the number of optional subjects and faculty requirements is the same with a three-major program as with the single major program. To the extent that there are multiple preparations, they can be converted into options without increasing the teaching load so long as the optional courses are completely filled so that the same total number of class meetings is adequate. Of course, some options will be more popular than others, and it is consistent with this proviso that several sections of one option can be offered but only one of others.

Table VI-5 shows the number of additional options that might be available by converting multiple preparations in optional subjects, for the case of three majors, the 100-25 class size policy and a limit of three classes based on one preparation. Only in colleges with 1200 or more engineering students are there significant zero-cost possibilities. As the three-class limit has the effect of increasing the number of preparations, the number of zero-cost options is also increased.

Colleges may wish to add options to the curriculum even if it requires additional faculty. One way of expressing a policy on options is the number of courses available to the student for the course he is required to take. Choice combinations can be quite complex, including one out of two, three, etc.; two out of three, four, etc. Sometimes the options lie between course combinations (e.g., pairs of sequentially related courses) and sometimes there are special restrictions. The simplifying assumption has been made that options are restricted to the series, one out of two, three, etc., and groups of options are unrelated; that is, there is no pool of options from which a given number can be selected.

The options policy considered here is for every optional course students have three to choose from. As there are no

TABLE VI-5

NUMBER OF OPTIONAL COURSES THAT CAN BE ADDED TO CURRICULUM WITHOUT INCREASING TEACHING LOAD, BY DISCIPLINE, 200 to 3200 STUDENTS

	Number of Students							
Discipline	200	400	600	800	1200	1600	2400	3200
Engineering								
Engineering Science	0	0	0	0	0	7	7	14
Electrical	0	0	0	12	12	27	39	66
Mechanical	0	0	0	1	1	20	21	41
Civil	0	0	0	0	0	11	11	22
Science								
Mathematics	0	0	0	1	1	8	10	18
Physics	0	0	0	1	1	5	6	11
Chemistry	0	0	0	0	0	2	2	4
General Education								
English	0	0	0	0	0	3	3	9
Fine Arts/Philosophy	0	0	0	0	0	0	1	2
History	0	0	0	0	0	1	1	4
Social Sciences	0	0	0	0	0	3	3	6
Health and Physical Education								
Health	0	0	0	0	0	0	1	2
Physical Education	0	0	0	0	0	1	1	4
TOTAL	0	0	0	15	15	88	106	203

alternatives to specified courses, the courses that must be added to the curriculum to implement this policy are two times the number of options. There are no options in the science courses; there are some in general education and physical education, but there are principally "technical options" in the student's major subject.

By comparing Tables VI-4 and VI-6 it will be seen that the effect of the one-in-three options policy is to increase the number of engineering subjects offered from 57 to 81, to double the number of general education subjects from nine to 18, and to increase the options in physical education.

The faculty requirements for this increased curriculum have been worked out for the model of three disciplines, a 100-25 class size, and three classes per preparation policy. It has been necessary to make some assumption as to the distribution of students among the available options; as with large student bodies, some options must be offered in multiple sections (especially upper division engineering subjects with a 25-student class size limit). Of the three options offered, one is assigned 50 percent of the students and the other two 25 percent each. It is plausible that actual experience might show such a distribution, although an actual empirical law is lacking.

Table VI-6 shows the following increases in engineering and total faculties that result from the above are:

	Number of Students							
	200	400	600	800	1200	1600	2400	3200
Engineering	5	4	3	3	6	0	5	0
Total Faculty	5	4	3	3	7	1	8	0

As before, the irregularities are the result of discontinuities resulting from operation of constraints. It follows from Table VI-6 that the 3200-student college can implement the option policy with no increase in teaching load at all. Of course, for the 200-student college an increase of five in faculty numbers is fairly significant.

Conclusion

The models of different curricula described in this chapter show how faculty requirements are affected by curriculum characteristics, including the number of major programs offered, the number of subjects, the number and distribution of students. The assumptions which have been incorporated in alternative models have led from an austere barebones model which would provide an accredited engineering program with minimum faculty requirements and minimum cost, but which possibly could not attract an adequate faculty or sufficient students, to a reasonably attractive program allowing a choice of three majors, a three-for-one spectrum of optional subjects, classes never

TABLE VI-6

MINIMUM FACULTY TO OFFER PROGRAMS LEADING TO BS IN ELECTRICAL,
MECHANICAL AND CIVIL ENGINEERING, AAUP FACULTY LOAD STANDARD,
MINIMUM ACCREDITED CURRICULUM AND OPTIONAL SUBJECTS AVAILABLE IN RATIO OF THREE TO ONE,
CLASS SIZES LIMITED TO 100 AND 25, FOR 200 to 3200 STUDENTS

Discipline	Number of Subjects	Number of Students							
		200	400	600	800	1200	1600	2400	3200
Engineering									
Engineering Science	7	3	3	3	3	4	5	7	10
Electrical	24	6	6	8	10	15	19	28	37
Mechanical	27	7	7	8	8	11	14	22	28
Civil	23	6	6	6	6	7	8	14	16
SUBTOTAL	81	22	22	25	27	37	46	71	91
Sciences									
Mathematics	6	3	3	3	3	4	6	8	11
Physics	4	3	3	3	3	3	4	5	7
Chemistry	2	3	3	3	3	3	3	3	3
SUBTOTAL	12	9	9	9	9	10	13	16	21
General Education									
English	2	3	3	3	3	3	3	3	4
Fine Arts/Philosophy	3	3	3	3	3	3	3	3	3
History	6	3	3	3	3	3	3	3	3
Social Sciences (Economics)	7	3	3	3	3	3	3	4	4
SUBTOTAL	18	12	12	12	12	12	12	13	14
Health and Physical Education									
Health	1	1	1	1	1	1	1	1	1
Physical Education	6	1	1	1	1	2	2	3	3
SUBTOTAL	7	2	2	2	2	3	3	4	4
TOTAL	118	45	45	48	50	62	74	104	130

exceeding 100 (and these often supplemented by recitation sections and laboratories) with many no larger than 25. At the same time, the faculty has teaching loads not exceeding nine semester hours and preparations falling under the AAUP standard of four per year, a minimum of two colleagues in their discipline, even in nonengineering subjects. The most elaborate program model would require a faculty of 45 for an enrollment of 200 which is obviously impossible to support financially. But it would take only 130 faculty--less than three times as many--to teach 3200 students or 16 times as many. At this level, the student-faculty ratio is nearly 25 to one.

Since faculty salaries are the most important single cost in higher education, these data argue strongly for large programs. Below 1200 students, or a graduating class of about 300 per year, it would appear that faculty requirements alone would make undergraduate engineering education impossibly expensive.

There are some ways of reducing cost. The most practical for small programs is for engineering education to be associated with a general university. In this way, small programs need not be burdened with an underutilized faculty in the sciences and general education. There is less advantage for a large engineering program. The reason is that if there are only 50 engineering students per year who need to take freshman English, this requirement in a general university requires only one-sixth or one-third of a single English professor's teaching time, and not a minimum faculty in English.

Another way is by relaxing the postulated constraints. The first constraint to go would probably be the three-man limit in a discipline; indeed, this constraint is already inoperative in a general university. The teaching load constraint can also be relaxed. Faculty can teach a number of disciplines instead of just one. Class size can be increased. One possibility is to restructure the curriculum so as to increase the portion of courses taken by all engineering students. It may not be absolutely necessary to have separate introductory courses for electrical, civil and mechanical engineers, although if there are enough students, such course tailoring is costless and presumably advantageous. All will reduce faculty requirements, though at some point the quality of the education offered drops to the point where accreditation is endangered. And accreditation itself may be a dispensable constraint.

Three other possibilities must be mentioned. One is that real savings may be available through the joint performance of undergraduate and graduate education, through education and research. These will be discussed in the next chapter. The second is the illusion of moderate cost that may result from accounting practice. By crediting engineering education with every possible revenue and allocating cost elsewhere (including cost of facilities and treating overhead of all kinds as general university expense), small scale engineering education can be made to appear self-sustaining. The third is that in a general university with considerable slack capacity, the incremental cost of adding or dropping an engineering program may be very low. Since the minimum faculty in the baseline program was 33, there is definite potential for cost saving in program austerity.

In every case the faculty number specified is the minimum that can perform the education function described. Any employment of more faculty to provide equivalent education is inefficient. If, in any college, more faculty are being used, it may be possible to reduce faculty without degrading the quality of education by using the faculty more efficiently. Consider the case vis-a-vis the last model described. This may involve increasing class size--but not beyond 100 in lower division classes or 25 in upper division classes. It may involve reducing course offerings--but not below the point where the student has less than three alternatives for each optional subject he must elect,

Of course, there are educational values in classes smaller than 100 and 25 and in a larger range of options, as well as other attributes not yet considered. A program with more faculty may be efficiently utilized for an even further enriched program. But there are probably some colleges which are not efficient in terms of what they offer.

In any event, there would appear to be a lower limit to the saving that can be accomplished through reducing the amount of program enrichment. These limits are sufficiently severe for the very small college as to suggest that they may not be able to become financially viable by simplifying and economizing on their programs. And for them it is disheartening that the kind of enrichment that is impossibly expensive for them may not add at all to the cost of a large school. This was the case with increasing the number of optional subjects, for example.

VII. THE EFFECT OF GRADUATE EDUCATION AND RESEARCH

The Graduate Education Model

A model for graduate education in electrical engineering that parallels that for undergraduate education can be developed in the same way. Initially, an isolated graduate program would be postulated, unconnected with an undergraduate program or a general university. The minimum curriculum which would enable students to obtain an advanced degree would be specified, and using AAUP standards for graduate teaching (which differ slightly from those for undergraduate teaching) a minimum faculty, distributed by discipline, would be developed as a function of the number of students. Alternative class sizes, the number of optional subjects, etc. would be explored as before.

The next step, to examine the effects of combining undergraduate and graduate programs in one discipline--probably electrical engineering--would exactly parallel the procedure of combining programs in several undergraduate engineering majors, described in the last chapter. A further more complex analysis would deal with graduate and undergraduate programs simultaneously for three majors each.

A priori, one would suppose that the faculty would not increase proportionately with the number of undergraduate and graduate degree programs--just as it was not tripled by changing from one to three undergraduate majors. There are, however, some differences in the characteristics of graduate programs and combinations with undergraduate programs which need to be considered.

One difference in graduate education is the extent to which graduate teaching is narrowly specialized. While it was reasonable to postulate that any professor of electrical engineering could teach any undergraduate electrical engineering course, this is less reasonable for graduate courses. Special fields in electrical engineering need to be treated as if they were separate disciplines. However, if a college needs a specialist in switching circuits for one or two courses in its graduate program, he would be able to teach general courses and undergraduate courses, although he may not be suitable for teaching graduate electromagnetic radiation. Of course, faculties for the graduate and undergraduate programs can overlap, and complexities of disciplinary constraints increase the tediousness of faculty assignment routines.

A second difference is the smaller proportion in graduate instruction of courses taken by all students regardless of their major. In an undergraduate program, over half of all courses are taken by all students, and this allows economy of faculty in the smaller schools. But the specialization in graduate programs largely rules this out; furthermore, there are often limited opportunities for classes combining graduate and undergraduate instruction.

Typically class sizes are small at the graduate level. Terman has suggested that this has become a tradition through habit, since once there were rarely enough graduate students at any one place to permit large classes. He questions whether quality graduate instruction requires small classes.

Another difference is the proportion of classroom instruction versus thesis supervision. The amount varies greatly according to the college; theses are not always required and sometimes not even allowed at the MS level, though they are an inevitable requirement at the PhD level.

As with previous analyses, some economizing in faculty requirements in operating graduate and undergraduate programs may be shown, even aside from the availability of teaching assistants--the source of other cost advantages. The amount of this saving will depend on:

- the overall scale of the educational establishment
- the proportions of students in various disciplinary areas
- the proportion in graduate and undergraduate programs.

If analyses of previous models are paralleled, the greatest economy would be in the smaller programs, and there might be no economy at all in large programs.

The Minimum MS Program

Guidelines for accredited advanced degree programs are virtually nonexistent as accreditation standards apply to the first degree. A typical master's program requires a minimum of 24 semester hours of work plus a thesis that is considered equivalent to six semester hours of work. Additional course work is required of students who do not have the necessary prerequisites, and sometimes course work is substituted for the thesis requirement. Depending on the rigidity with which requirements are interpreted, the actual number of courses taken in an MS program might run from 24 to 36 semester hours. Credit is sometimes allowed for graduate work done elsewhere, though the amount may be limited. Time limits for the entire program are sometimes established, such as three years for full-time students or five years for part-time students. In a combined graduate and undergraduate program, additional courses might well be those taken by advanced undergraduates, and not additions to the curriculum.

Graduate MS study generally allows specialization within a broader field, such as electrical engineering. Areas of specialization might be: networks; electronics; fields and waves; communications; computer science; systems and controls; medical electronics. If all of these were offered, it would be necessary to develop a sequence of 24 to 36 semester hours of work in each. To some degree, faculty would specialize in one or the other of these general areas, though some may teach in several.

Since the AAUP teaching load for graduate instruction is four preparations and four class meetings, a baseline graduate program leading to the MS and allowing a single option could be provided by two additional faculty members. Of course, not all graduate teaching would be done by two men, but the effect of graduate teaching spread among faculty combining graduate and undergraduate teaching would result in this increase in the total faculty requirements. With a class size of 25, such an increase could handle graduate classes to 25 students; for 26 to 50, four faculty members would have to be added, and so on. If two areas of specialization were to be offered instead of one, the numbers of additional faculty would be doubled, and so on. These numbers would apply regardless of the size of the undergraduate program. Where enrollments are sufficiently large so there would need to be multiple preparations, it would of course be possible and attractive to add optional subjects instead, at zero cost.

The thesis requirement also generates faculty workload. Such supervision in a normal amount is part of the graduate school faculty workload recognized by the AAUP. The normal amount does not require additional faculty or relief of other duties. The number of MS theses per year per faculty member generated by a school with an average student-faculty ratio may be taken as normal. This might be about five to ten, and previous models have shown that in very large schools the minimum faculty may imply a 28:1 student-faculty ratio. The effect on workload would depend on the number of graduate students relative to the whole faculty, and if moderate, the additional workload will not be excessive.

To illustrate, consider a university in which graduate enrollment is one-quarter of total enrollment; where the MS program is typically three years. Thus, with an enrollment of 800, 200 would be graduate students, and 150 BS and 67 MS degrees would be granted every year. The minimum engineering faculty for a program with 600 undergraduate students in electrical engineering is 13 with seven in electrical engineering. The minimum graduate program consists of 8 three semester hour courses with an enrollment of 67 in each. Even if graduate courses can be as large as 50 students, each course would have to be offered twice. The 16 graduate course meetings would require an additional faculty of four in electrical engineering, bringing the total faculty in electrical engineering to 11, and the total engineering school faculty to 17.

Comparative Faculty Requirements of Graduate and Undergraduate Students

It is interesting to compare the effect of adding a 200-student graduate program with 200 more undergraduates in a college offering only electrical engineering. Table VI-3 showed how 600 undergraduates could be handled by a minimum college faculty of 36. Thus, the following comparisons apply:

	Faculty for 600 Undergraduates	Additional Faculty	
Discipline		Adding 200 Undergraduates	Adding 200 Graduates
Electrical Engineering	7	2	4
All Engineering	13	3	4
Entire College	36	5	4

Thus, the faculty requirements for an equal number of undergraduate and graduate students are one faculty member less for the graduates, although they are concentrated in electrical engineering, where graduate work is concentrated. But, a critical element in this comparison is the assumption that graduate class sizes can be as large as 50 students. If the graduate classes were held to 25, six faculty members would be required, which is more than would be needed for expansion of the undergraduate program. If the upper division undergraduate classes were also held to 25, going from 600 to 800 students would add three or more to the minimum faculty, but the comparison would be basically unchanged.

It would appear that graduate education does not inherently require more faculty. Also, the semester hour requirement of an MS program is small compared with a BS program, and total faculty per MS graduate consequentially are less than per BS.

Graduate Students as Teaching Assistants

There is little to suggest any economy in faculty numbers from the joint operation of undergraduate and graduate programs. Indeed, there are two possibilities: very small programs; and use of the combination graduate student-teaching assistant.

With small undergraduate programs, where the course requirements do not utilize the faculty fully, it might be possible to obtain more effective utilization through a joint undergraduate and graduate program; however, these opportunities are minimal with large faculties and student bodies, and in view of administrative workloads and other possibilities for the utilization of faculty slack in administration, the advantage may not be great.

In a strictly undergraduate program, the nonavailability of teaching assistants was one difficulty. It was shown in Chapter III that the full-time equivalent number of TA's needed to man recitation sections ran from nine with an enrollment of 200 students to 99 with an enrollment of 3200. Especially with small enrollments, faculty slack time was sufficient to fulfill completely the requirements; however, the recitation section teaching function can be satisfied by a lower-skilled person, and faculty could be diverted to graduate teaching if TA's were available. Parenthetically, as the table on page III-18 showed, the greatest need for TA's is in mathematics and science. If graduate engineering students would make satisfactory TA's in the sciences, this point creates no difficulties. How many TA's will be available depends on the size of the graduate program and the portion who wish to supplement their income as TA's. In some graduate schools the proportion is high, but in schools heavily involved with part-time students, the proportion is often low.

While TA's are not a sufficient argument for a graduate program, it is of interest to see how large a graduate program would supply the need. TA's generally teach on a half-time basis. For all recitation sections in engineering and the sciences to be met by TA's the number for various undergraduate enrollments can be translated from the table on page III-18. If 10, 20 and 30% of graduate students are available as TA's, the graduate enrollment that will permit requirements to be fulfilled are as follows:

	Number of Undergraduates					
	200	400	600	800	1600	3200
Number of Half-Time Teaching Assistants in Science and Engineering	12	24	30	42	84	162
Graduate Body that would Produce this Many TA's if						
10% serve as TA's	120	240	300	420	840	1620
20% serve as TA's	60	120	150	210	420	810
30% serve as TA's	40	80	100	140	280	540

Fulfilling the requirement will often be possible, in view of the ratio nationally of graduate to undergraduate students in engineering and the proportion of graduate students seeking part-time academic employment. Within broad limits, the portion of graduate students who will be available as teaching assistants is determined by the policies followed in admission of graduate students, but use of TA's is also severely limited by the availability of educational grants and scholarships.

Research and Faculty Requirements

Most engineering departments have contracts and university funds which can be used for research by faculty and graduate students. Time for research generally is used to reduce teaching loads. Given the total number of courses that must be met and the number available from each faculty member after adjustment for research time, total faculty requirements can be recalculated. For example, if all engineering and science faculty had a one-third reduction in teaching load, they would be available for four class meetings a year instead of six. The minimum faculty can be calculated with faculty assignment sheets; except for discontinuities, the relationship is straightforward, and one-third in teaching load increases faculty requirements by 50%.

It would appear that accreditation and the AAUP standards are concerned both with the level of output and the amount of time set aside for research. No research output is possible without time being spent, and too heavy a teaching load makes research performance impossible.

The AAUP standards clearly postulate that with a nine-hour teaching load that faculty have some time for research performance, but do not say that the amount would be sufficient to warrant accreditation. The research performance that would be expected of a college of 200 is hardly that which would be expected of a larger college. Many accredited colleges have extremely limited research programs. Indeed, the Cartter data show that the percentage of time for research of engineering faculties is below the average for all disciplines.

If more research output is desired or needed for accreditation, there must be faculty released time and reduction in the teaching loads. However, the relationship between output and amount of released time is not determinable from available data. The California survey did not distinguish contract or grant-supported research from that which would be expected without such support. The Cartter report obtained information on research output as well as research time, output being measured by numbers of publications, but was not published in a form that was amenable to analysis. It would appear that the relationship would vary by discipline and age or experience of the researcher.

To find the functional relationship between the amount of research and total faculty, holding constant the amount of graduate and undergraduate teaching must remain for future study. The theoretical model might develop a chain of causations, released time to research performance to publications and other results. Adequate faculty performance can be specified as some minimum number of publications in accepted professional journals, and an estimate could then be made of the amount of time and financial support necessary in order to enable a faculty to produce that output. On the assumption that faculty will work a certain number of hours per week, given time demands of teaching, the amount of teaching which is consistent with this level of research performance could then be estimated.

Of course, the means by which faculty are motivated to perform research are crucial. The management of faculty research has hardly been discussed in the literature, and the literature on management of wholly research organizations would need substantial reorientation.

Faculty Quality and Program Characteristics

There are important cost-influencing variables besides faculty numbers in a broader study. One is faculty quality, about which the analyses of this paper have not made any assumptions. Just as the minimum curriculum was used as a base, so could the minimum quality faculty. But faculty quality is strongly related to such attributes as curriculum, student calibre, interesting graduate programs, research opportunities, facilities--and of course salary. A college must have a desirable mix of attributes if it is to attract and retain a high quality faculty. It is possible that the baseline program described above would not be consistent with retaining a faculty sufficiently good to warrant accreditation and therefore understates the true minimum program.

Possibly lack of many traditional elements of a prestigious program can be offset by offering higher salaries at a lower total cost than actually supplying the attributes. That is, a young faculty member may say that at comparable salaries, research, etc., will influence his choice of which position he accepts, but if a school offering only an undergraduate baseline program offered x thousand more than a school with these attributes, he will accept that position. Thus, with an engineering and science faculty of 36, it would cost $72,000 to offer a salary which is $2,000 above the average. Would this be sufficient to offset the unattractive features of the program sufficiently that an accreditable faculty could be obtained? This is a point to investigate.

It seems likely that attempting to attract faculty by supporting research out of college funds is not likely to be the most cost-effective approach. Research is expensive; $72,000 might permit two man years of research, which would not go far among a 36-man faculty. However, contractual research can be used to obtain an attractive research program at no cost to the college, and an effective contract research strategy requires self-supported research which provides the demonstration of expertise that makes it possible to get research grants and contracts. When account is taken of the financial leverage gained per dollar of university funds in a well-managed program of self-supported research, the cost-effectiveness of research looks very different. Suppose that for every dollar of university-funded research, it was possible to obtain research contracts and grants of $3.50. Then, the attractive power not of $72 thousand but $252 thousand is relevant in the tradeoff calculation between higher salaries, amenities, curriculum structure and research opportunities.

Since competent researchers are in demand, the possibility of a high multiple is linked with paying higher-than-average salaries in the first place! A plausible hypothesis is that the multiplier just described is a function of salary level relative to other employers. This only slightly complicates the tradeoff calculation, and the identification of the optimum combination. Competence obtained in contract research as well as in self-supported research influences success in winning new contracts, and the multiplier should relate to both types. There is a dynamic interrelatedness between self-supported research leading to later success in contract research which, in conjunction with later self-supported research, leads to further contracts, while the attractiveness to faculty of the program changes continually as the level of research progresses upward.

In any event, the teaching workload cannot be so large as to allow no time for activities that permit a faculty to achieve and retain minimum quality. An excellent extension of the methods used here would be to calculate the time and other requirements that would permit a faculty to demonstrate acceptable quality. If research output is the demonstration, the relationship between time on research and output would be useful. Nothing of this sort is presently available.

VIII. POSSIBLE EXTENSIONS OF THE MODELS

Dynamic Adjustments

One of the simplifications of the models has been the steady state assumption, meaning uniform class size, without attrition, in-transfers or growth. It is common for the class size to drop off in the successive four years in an engineering program, and for enrollments in lower division subjects to be somewhat larger than in upper division subjects. A model might, therefore, postulate the number of 50-student sections, or whatever limit is used, to be reduced. There is no difficulty in calculating faculty requirements under assumption of given attrition rates. Since much of the first two years of an engineering curriculum is in the sciences, the effect of attrition is to enlarge science faculties relative to engineering faculties.

Sometimes engineering colleges change size, and the minimum faculty changes accordingly. If a college is growing steadily, each succeeding class will be larger than the one before. Not only will the faculty have to increase yearly, but freshman and sophomore classes will always be larger than the junior and senior classes. The effect on balance among disciplines is, therefore, similar to that of attrition, and also will produce a relative enlargement of faculties in sciences and subjects taken by lower division students. The combined effects may reinforce each other.

Where growth patterns are irregular, class sizes and faculty requirements are specific for each particular year and the time flow of increasing faculty requirements by discipline must be calculated year by year from given assumptions as to attrition, in-transfers and growth.

Such calculations can be immensely useful in university planning. For example, an increase in the size of an entering class may be hoped for as a result of a recruitment campaign. The science and general education faculties teaching first-year subjects might be tentatively increased to cope with the possible inflow, but the engineering faculties would not have to be increased for several years--until the students reached the part of their program that focused on engineering. There is no immediate need for increasing engineering faculties in anticipation of increased freshman engineering enrollment.

Faculty requirements can be worked out for any desired set of assumptions. For very large, complex universities, especially where the range of options is very large, computerized models for predicting class enrollments may be useful. There are several in which student course selection is represented as a Markov process. Where many alternatives are open to the students, such models can be of considerable use in planning and deal with problems that have been set aside in our models by assuming program rigidity and lack of options.

Effect of Classroom Capacity Constraints on Minimum Faculty

Anything that reduces the class size may have the effect of increasing minimum faculty. This was observed in the lowering of maximum class size from 50 to 25, or raising it from 50 to 100. Limits based on teaching policy had that effect, and constraints imposed by the classroom size may also raise faculty requirements. For example, if a college has few 100-student classrooms, and holds more sections, using more faculty, it must limit the number of large classes. If a classroom can be used eight times for a Monday-Wednesday-Friday schedule and eight times for a Tuesday-Thursday-Saturday schedule (the latter being most suitable for courses with less than three lecture sections and recitation or laboratory sections scheduled at other times) each 100-student classroom can meet the needs of 16 courses. For the 3200-student college, the distribution of classes of 100 by discipline is:

Engineering Science	48
Electrical Engineering	4
Mechanical Engineering	4
Civil Engineering	2
Mathematics	32
Physics	24
Chemistry	16
English	24
Fine Arts/Philosophy	8
History	16
Social Science	8
Health	8
TOTAL	194

If a college of this size had fewer than 13 100-student-capacity classrooms (from 194 divided by 16 and rounded up), it would be obliged to schedule some courses in smaller sections and to increase the number of faculty. Physical education is omitted as not being a classroom subject. There is, of course, a straightforward relationship between the number of classrooms and number of faculty which leads itself to cost-effectiveness analysis.

Faculty Numbers into Faculty Costs

The interest in the number of faculty lies principally in its significance in determining the total faculty wage bill. Faculty are a principal component of university costs.

There is enormous variation in the salaries of faculty members with comparable formal qualifications. Of course, in any one institution, salaries are strongly associated with academic rank, but there are few criteria for rank and few guidelines as to what portion of a faculty can be in various ranks. As higher ranks do not stand in a clear supervisory relationship to junior faculty, the thinking that goes into rank proportions in industry does not apply. Enormous differences in the distribution by rank are found in American colleges.

Structure by rank may be more a function of personnel policy than teaching skills or formal qualifications. While rank tends to be an indicator of experience and achievement, it is by no means certain that the higher-ranked faculty member will be more effective as a teacher than the lower-ranked one--especially one who was promoted for research performance.

Probably most individuals' teaching competency increases with experience up to the point where their store of knowledge approaches obsolescence. In engineering, this point can come early.

The translation of faculty numbers into a faculty salary bill requires some assumed proportion of faculty among rank and an average salary for each rank. Typical experience can be used for a guide. The annual AAUP faculty survey can be used to establish typical rank distributions and salaries. With them a salary bill can be estimated for accredited institutions.

This is a comprehensible and manageable approach. An alternative would be an optimization-oriented approach which sought to determine for given levels of research and teaching background a) what a college needed of each rank, seeking to minimize the number of high ranking and therefore expensive faculty and b) what it would need to pay to obtain a faculty capable of performing in an accreditable way. The total salary cost of the faculty determined in this way would be the baseline, or minimum salary, bill for faculty when applied to baseline or minimum faculty. To this should be fringe benefits. To calculate minimum faculty cost is by no means a recommendation that a policy of paying the minimum should be followed, but it does make possible to proportion the actual salary bill into two components, one of which is the unavoidable minimum and the other the portion above the minimum for which faculty performance above the minimum should be expected. The cost-benefit comparison of faculty cost versus performance can focus on the increment of cost vis-a-vis the increment of results.

In an optimization-oriented analysis of faculty costs, salary is especially relevant. The problem is to select the least-cost faculty that will meet specified needs. Every potential faculty member combines teaching, administrative, and research skills. Each of these has a subject-area dimension, a problem-orientation dimension and a personal-growth dimension. For example, the subject-area dimension in teaching is the discipline or specialty. The problem-orientation dimension refers to skill with large or small classes, undergraduate and graduate students; the growth dimension refers to the pattern of change in personal skills and serves to distinguish between a young man who will learn from experience and an old dog who is unlikely to learn any new tricks.

A department can specify its needs by subject-area, problem-orientation and growth needs, and seek to identify the mix of available individuals who will meet these needs at least cost. The analytical task is recognizable as a program in linear programming. Of course, the solution is much simpler if it can be specified that professor X will be available this year and in the future for a specific salary, or that Joe Y definitely will come for a certain salary, but incorporating uncertainty into the model does not make it impossibly complex.

In such an analysis, a first solution might be made without constraints reflecting the tenure system. Next, additional constraints reflecting tenure might be used in a recalculation, and any increase in cost determined; this would be the cost to the university of the tenure system--an amount which might be allocated in the university budget to faculty fringe benefits.

The dynamics of faculty compensation policy are crucial for the university. Low salaries make it impossible to recruit satisfactory faculty. Sometimes rank substitutes for salary, but at a long-run cost in faculty quality. Faculty, once hired, expected regular increases in rank as well as in salary. The university that cannot accommodate these expectations loses good people, and quality deteriorates. Thus, a rank and compensation policy needs to take into account the lifetime career that can be held out for newly hired faculty that the college hopes to keep. Working out a progression of salary and rank which can be maintained as individual faculty members progress through ranks to departure or retirement is a difficult matter.

Among the tradeoffs that must be considered in working out faculty numbers and faculty salary costs is the teaching load. It is common in many of the more prestigious schools to assign somewhat lighter teaching loads than the AAUP standard. They are able thereby to obtain higher quality faculty, by freeing faculty for more research performance. Given the credo of professional academia, research will always be a preferred activity. Teaching load may be a tradeoff with salary in obtaining and retaining good faculty, and there are reasons for suspecting that lightened teaching loads with research opportunities are especially persuasive arguments for faculty with outstanding potential. In any event, lightened teaching loads mean that a larger number of faculty must be used for the teaching function.

Rank distribution may, under optimization schemes, vary with the overall faculty size. The critical functions of senior faculty are judgment, leadership and providing continuity. Even the smallest department needs persons who provide these qualities, but once a few are available, it may not be critical that additional faculty show these qualities in the fullest. A large department, adequately equipped with senior people, can control and put to good use a considerable number of less experienced junior people who come cheaper.

Conclusion

Material has not yet been developed for translation of faculty numbers into costs, but it is frequently possible to get a view of the "ballpark" from rules of thumb. A common rule is to assume that overhead and other costs are about 100 percent of direct salary costs. In an engineering school, direct salary costs are faculty, teaching and laboratory assistants and supportive personnel. Assume that they are equal in number to faculty and are paid on the average one-half as much. Then, total cost is 200 percent of 1 1/2 times total faculty salaries, or three times the salaries. Let average per capita faculty salary equal $20,000, so that the total university cost per faculty member is $60,000. Dividing total cost estimated in this way, for the minimum faculty, into the number of students produces a rough rule of thumb estimate of university costs per student as a function of number of students as follows. For the case of the three-major, 50-students per class program, data per student would then be:

	Number of Students							
	200	400	600	800	1200	1600	2400	3200
Student-Faculty Ratio	4.9	9.8	14.6	16.7	23.5	22.3	25.8	24.2
Costs Per Student ($000's)	12.3	6.2	4.1	3.6	2.5	2.6	2.3	2.5

If the figure of $60 thousand per faculty member is not too high, these data suggest that even in the most favorable circumstances only colleges with 1200 or more engineering students will be able to keep costs in line with the tuition income that can be obtained from students.

For the college which teaches only undergraduate engineering, the mathematics of cost and revenue from the teaching program are inexorable, and income must match costs in the long run. However, undergraduate education in engineering may be combined with some other activities, such as graduate education in engineering, general university education, or contract research. Such joint programs may sometimes provide a surplus of revenue which can be diverted to support a high-cost undergraduate engineering program, so that it can be maintained as part of the larger enterprise. There are sometimes possibilities for economies in joint operation of engineering education and other programs which produce real cost savings as well; however, the analyses reported earlier suggest that they exist mainly in small programs which are far above the cost level of economic viability and are modest at best. That this is so may be difficult to determine from formal accounting systems. For example, if the total tuition income from engineering students is compared only with the cost of the engineering faculty, the illusion is created of even small engineering programs being in financial balance.

The data show how expensive it is for the small engineering school to expand the number of major areas which it offers. There is a strong case for engineering schools with fewer than 1200 students to hold down the number of major areas to one or at most two. There are, of course, objections to this procedure, but it should be obvious also that it is expensive to proliferate programs if they will require specialized faculty. Such majors as computer science or medical electronics are intermediate cases, since they represent not whole new programs but a particular selection of options within electrical engineering. However, as was pointed out earlier, the small engineering school cannot add very many options without incurring additional faculty costs, if any at all.

Outside the engineering school, the impact on the university of the number of major programs the engineering school chooses to offer is quite modest and arises only where science and subjects such as economics in the civil engineering program are required in different amounts in different programs. Impact can be seen in the case of 3200 engineering students in a general university; where the teaching of 16 faculty members in the mathematics department would be required if all of the students were in electrical engineering, but 13 if they were divided among the three majors. The effect on physics is only an increase of one faculty member for the all-electrical case. Obviously the larger the proportion in civil and mechanical engineering the less the requirements in mathematics and the more in economics. These shifts in the composition are minor compared to the effect of the total overall number of engineering students.

APPENDIX

Calculation of Faculty Requirements

In preparing this paper, many tables were developed by completing the table following for each cell--that is, for each combination of an academic discipline, a number of courses in the discipline, total student body course enrollments and a class size limit. Faculty assignments for minimum teaching load have been worked out by hand. While tedious, the calculation is not difficult.

The recommended procedure is 1) to mark the number of courses by a vertical colored line (pasting forms together if they exceed 16), 2) enter enrollment, size limit for each course and by dividing through, find and enter the minimum number of sections for each. As step three, enter the total courses and sections in the sub-table at the bottom left, and find the minimum faculty. Drawing a colored horizontal line on the table, delineate the working part of the table. Step 4 is to determine the minimum number of preparations for each course by assigning the maximum allowable number of sections (generally six or three in this paper) to the first faculty member for the first course, the remainder--if any--to the second, third, etc. faculty members until the required number of sections have been accounted for. Repeat the procedure

FACULTY ASSIGNMENT PLAN __________ DEPARTMENT, _____ COURSES AND STUDENT BODY OF _____

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Constraints Check		Determinants of Teaching Hours							Total Teaching Time
																			Number of Courses			Number of Students				
																	Total Sections	Total Preparations	Direct	With Recitation Sections	With Laboratories	Total	Direct	Through TA's	Laboratories	
Course Description																										
Course Characteristics*																										
Total Course Enrollment																										
Maximum/Section																										
Minimum # of Sections																										
Actual # of Sections																										
Faculty Member																										
1																										
2																										
3																										
4																										
5																										
6																										
7																										
8																										
9																										
10																										
11																										
12																										
13																										
14																										
15																										
16																										
																Totals:										

Teaching Load Constraints:
Sections ☐
Preparations ☐
Minimum Faculty Constraint:
Sections/Sec. Constraint ☐
Preparations/Prep. Constraint ☐
Least Allowable Faculty ☐
Largest Faculty Constraint ☐

Faculty Utilization Summary

	Sections	Preparations
Available		
Assigned		
Excess		

Total Standard Teaching Hours _____
Total Actual Teaching Hours _____

*Course characteristics: taught by
D - faculty member only
I( ) - faculty member and TA's
L( ) - faculty member and lab assistants
(enter section or lab size limit in brackets)

for the other courses. By adding horizontally that the number of different courses and sections for any faculty member, check that workloads do not exceed constraints. As step 5, add up total preparations and sections of the whole faculty and enter it in the "assigned" row in the faculty utilization summary sub-table. The "available" row is the number of faculty times the preparations and sections available per faculty member--obtained from the sub-table at the left. Subtract assigned from available to determine excess preparations and class-meeting capacity. As step 6, ascertain that there is not some other allocation of faculty among courses that will result in a greater excess. There will not be if as many as possible of the faculty members who prepare a course at all are assigned sections for each preparation up to their section-meeting constraint; sometimes other constraints make this impossible, and sometimes the minimum assignment pattern is not unique. The lower right-hand sub-table can be used to calculate the standard hours involved in the teaching, using the formula given in the text.

This table can be used flexibly--e.g., certain faculty members may be available for a nonstandard teaching load. A computer routine for making assignments and calculating minima should not be difficult and would be worthwhile if the table is to be used massively. If teaching hours are also treated as a constraint (as they have not been in this paper), calculating minimum faculty is considerably more complex.

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16. Abstracts

This study determines the faculty necessary for an accredited engineering curriculum as a function of the number of students, faculty workload and curriculum characteristics. A minimum faculty of 32 is required, and as the student body is increased from 200 to 3200, the required faculty increases 3 3/4 times; hence there are considerable economies of scale in engineering education. The study shows how number of faculty is affected by modification of the curriculum, number of areas in which students can major, number of courses, class size or faculty workload. Faculty requirements in small autonomous engineering colleges are shown to be excessive, and with small enrollments the advantage of being part of a general university is substantial. Where engineering enrollment is large, it is possible to maintain breadth of curricula, faculty workload well within AAUP standards and moderate class size although student-faculty ratio exceeds 25:1. The research method of synthesizing a faculty from basic requirements avoids undefined variations in program characteristics that would influence survey data. The method is flexible and generally applicable to university financial and manpower planning.

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